THE UNIVERSITY OF ALBERTA

GEOLOGY AND U DEPOSITS OF THE CHARLEBOIS-HIGGINSON LAKE AREA, N. SASKATCHEWAN

by

© Franco Piero Morra

A THESIS

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ABSTRACT

The thesis area lies in the Charlebois-Higginson Lake region, northern Saskatchewan, and forms part of the Churchill province of the Canadian Shield.

This thesis is intended as an interpretation of the geology, petrography and ore mineralization of the Charlebois-Higginson Lake Area.

Field evidence, supported by a detailed petrographic study of 155 specimens shows that:

(a) the great majority of the rocks present in this area are metamorphic. Also the granodioritic granofels, although previously interpreted as an igneous rock, is endemic, syngenetic and forms an integral part of the metamorphic complex.

(b) post-crystalline deformation is almost absent,only 8 samples showing noteworthy postcrystalline deformation (cataclasis). The rocks are considered to be mónometamorphics.

(c) the sequence consists mainly of metasediments and minor amounts of metavolcanics.

(d) most of the metamorphic assemblage belongs to the intermediate amphibolite facies of regional metamorphism, with presence of higher metamorphic conditions within the amphibolite facies range.

(e) starting retrogressive metamorphism and very slight potash migration were ascertained in some specimens of the thesis area. On the basis of the mineral composition, the

metamorphic rocks are divisible into seven major members, forming together the "Charlebois Lake Complex".

The uranium mineralization found in the granodioritic granofels and migmatite members consists primarily of uraninite associated with molybdenite and with minor amounts of magnetite, pyrite and pyrrhotite.

Geological considerations and radiometric evidence based on quantitative gamma spectrometric analyses of 70 samples for K, U, and Th determination, suggest that the mineralization present in the Charlebois-Higginson Lake area may have originally been of syngenetic sedimentary origin, prior to its metamorphism and that the parent rocks of the granitic and tonalitic gneisses of the area constitute the most likely source-rocks of the uranium deposits.

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CHAPTER I

INTRODUCTION

General Statement

The Charlebois-Higginson Lake Area was mapped during the summers of 1974 and 1975 by the writer, who was employed as a senior geologist by FOSAGO EXPLORATIONS LTD., to study the petrography of the region in detail, and to determine the economic potential of the numerous radioactive occurrences found there.

Object of this Thesis

This thesis is intended as an interpretation of the geology, petrography and ore mineralization of the Charlebois-Higginson Lake Area.

It is primarily based upon detailed geological mapping and sampling and subsequent laboratory studies, with the aim of determining: (1) the stratigraphic sequence and the structure of the complex, (2) the nature of the metamorphic rocks and their precursor lithologies and development, (3) the conditions of metamorphism, (4) the nature and origin of the uranium mineralization found within the metamorphic suite.

Methods Used

Field mapping was done on a scale of 1:16,000 utilizing a topographic map as a base, obtained from enlarged copies of aerial photographs.

Where possible, geological traverses have been completed every 1000 m, or less in areas of particular interest or complexity. Lake shore geology completed the basic information for the compilation of the general geological map.

Approximately 400 samples were collected from all the different rock-types present in the area, in order to obtain a complete representation of the local lithological variations.

In the mineralized areas, samples were collected along the trenches at 60 cm intervals.

Because of the limited time, only 155 specimens selected from the most representative ones and from each of the rock-types, were examined in thin section under the microscope.

Point counting was done on 48 specimens, with an attempt to select the most typical ones. An average number of 1600 points per slide were counted. Seventy specimens, chosen from fresh blasted rocks and within a range of 150 m from the mineralized area, were analyzed using gamma-ray spectrometer for U, K, and Th.

All the metallic minerals and their secondary products of alterations were analyzed using X-ray diffraction.

Location and Transportation

The Charlebois Lake Area is located in northern Saskatchewan, about 160 km west of the Manitoba border and 54 km south of the N.W.T.

Charlebois Lake and the adjacent area are reached most easily by float-equipped aircraft in summer, and by ski-equipped airplanes in winter.

The closest settlement with a regular air service, Stony Rapids, is situated 54 km to the southwest.

Stony Rapids is serviced by 'Norcanair' by scheduled flights of wheeled airplanes to La Ronge and to Prince Albert, 480 and 672 km respectively to the south, and to Uranium City, 160 km to the west, on the north shore of Lake Athabasca.

During the summer months it is possible to reach Charlebois Lake by barge from Fort McMurray, which is connected by a 560 km water route to Stony Rapids.

A canoe route connects Stony Rapids to Charlebois Lake, via Black Lake, Peterson Lake and Higginson Lake. Black Lake is also reached by a 24 km road from Stony Rapids.

The area mapped covers approximately 235 square kilometres, between latitudes 59°20'N and 59°30'N and longitudes 104°40'W and 105°00'W.

Topography and Vegetation

The topography of the mapped area is typical of the Canadian Shield, moderately rugged, with hills rising as high as 100 metres above lake level. The land is covered by numerous small-and medium-sized lakes (about 2 per square kilometre).

Drainage is to southwest. There are few steep cliffs, usually present close to the lakeshores and striking parallel to those shores. These mark fault zones and, more

commonly, the contact between two lithologically different rocks, the softer rocks having been gouged by the glaciers and now hosting lakes in the depressions thus created.

The ridges are in general underlain by amphibolite, granitic gneiss, granodioritic granofels, and migmatite, while the areas covered by lakes are generally structurally controlled by faulting or are formed by less resistant rocks, such as biotite gneiss and calc-silicates, that in places are visible along the shore of the lakes.

Extensive outcrops are only visible on the tops of the hills, which are generally composed of granitic gneiss. Swamps, muskegs and areas covered by boulder drift are very common as the drainage is very poor. This low ground, occupied by swamps, muskegs, and boulder drift, and also a very thick underbrush, created serious problems in mapping.

Eskers and glacial striae are numerous and indicate the last glacial event, about 10,000 years ago.

Some sandy beaches and sand dunes are present, usually adjacent to eskers.

The ground is permanently frozen below 150 cm and in some places ice was found under the moss.

Due to the northern latitude, the lakes are frozen from the beginning of October until the end of May.

CHAPTER II

REGIONAL GEOLOGICAL SETTING

Previous Studies

The first geological work in this region was performed by R.G. McConnel (1893), who traversed the south shore of Lake Athabasca in 1890.

A general geological mapping of the Stony Rapids and Porcupine River areas was done by G.M. Furnival (1940) in 1939. The Charlebois Lake area is situated near the western part of the Porcupine River map-area.

The area was then surveyed by prospectors and geologists because of the presence of low-grade uranium deposits.

The first complete geological mapping of the Charlebois Lake area was done by J.B. Mawdsley (1950), for the Department of Natural Resources, Saskatchewan, to determine the importance of numerous radioactive occurrences discovered in the district. He recognized the "Archean Tazin metasediments" in the quartzites, biotite schist, hornblende schist, and calcareous metasediments present in the area. The name "Tazin" was introduced by C. Camsell (1914) who made a reconnaissance trip from Lake Athabasca north along the Tazin River to Thekulthili Lake. Near the N.W.T. boundary he found remnants of a linear belt, an old series of stratified sedimentary rocks, which he named the "Tazin Series". These remnants were interpreted as being engulfed in a great composite batholith made up probably of two distinct types of granite, one gneissic and the other massive.

Mawdsley (1950-p. 9) considered the "pegmatite-granite, the granite, and the granite-gneiss", underlying more than two-thirds of the Charlebois Lake area, as intruding the Tazin Group and therefore younger. Mawdsley (1952) gave a petrographic description of the metamorphosed sediments and of the "intrusive granite". He distinguished four types of granite and granite-gneiss, on the basis of their K-feldspar : plagioclase ratios.

Further petrographic studies on the Charlebois Lake area rocks were carried out by G.L. Cumming (1952), and S.J.T. Kirkland (1952). Those authors were in agreement with Mawdsley's ideas concerning the distinction between the Tazin metasedimentary sequence composed by biotite and hornblende schist and gneiss, impure marble, quartzites, and calcareous rocks, and the younger intrusive fine pegmatite, migmatite, granite and granite-gneiss, which they called "Archean intrusive".

In 1957 Mawdsley's geological map of the area was published by the Department of Mineral Resources, Saskatchewan (Mawdsley, 1957). The author recognized metamorphic textures in what he previously had called "younger intrusive granite" (Mawdsley, 1952, pp. 368-370). A report summarizing the previous work done in 1950 in the Charlebois Lake area was presented by Mawdsley (1958). He pointed out that the oldest rocks are "highly metamorphosed sediments" grading into granitic gneiss, observing that "there is a

pronounced parallelism between the banded schistose and gneissic structures in the metasediments and in the granitic masses, and between most of their contacts". Mawdsley (1958, pp. 487-488), wrote that the granitic gneiss was strongly banded and that "the textures, in some places, are not typically igneous". (Mawdsley, 1958, pp. 486).

Cumming, Wilson, Farquhar and Russell (1955) dated the "younger pegmatite and migmatite bodies" using age determinations made on radioactive minerals. The results gave an approximate age of emplacement of 1,800 m.y. . Unfortunately no more age-determinations have been done in this region since then.

L.S. Beck (1969) presented a report in which he correlates and synthesizes the existing information and other writers' data on the regional geology and the uranium deposits of the Athabasca Region. The Charlebois-Higginson Lake area falls outside the region considered in Beck's report, but much of the information was used by this writer to make useful comparisons with adjacent areas, in particular the Beaverlodge area.

General Geology

The region forms part of the Churchill Province of the Canadian Shield and is underlain by a Precambrian assemblage of metamorphosed supracrustals.

The great majority of the area, about two-thirds, is underlain by both massive and more commonly, well foliated granitic and tonalitic gneisses. They usually form the cores of antiforms.

The remaining one-third of the area is composed of foliated and well banded migmatite, biotite gneiss, hornblende gneiss and pyribolite, and of more massive granodioritic granofels, quartzite, amphibolite and calc-silicate rocks. This assemblage is exposed along the shores of the lakes, occurring in synforms and enveloping the flanks of major antiforms. The belts are generally formed by alternating different lithological types, always parallel one with the other, and often presenting a gradational variation at the contact.

Pyribolite was hardly mappable on the scale we were operating (1:16,000) and therefore it was included in the hornblende gneiss-amphibolite category. For the same reason, biotite gneiss with incipient migmatization was included in the biotite gneiss category, and dioritic gneisses, gneissic granites and quartz-monzonite gneisses were included in the granitic and tonalitic gneiss category.

The mapped rock-types are:

a) granitic and tonalitic gneiss

b) migmatite

c) granodioritic granofels

d) calc-silicate rocks

e) hornblende gneiss and amphibolite

f) biotite gneiss

g) quartzite.

No age relationship has been definitely established within the rocks of the Charlebois Lake district, but field evidence suggests that the granitic and tonalitic gneisses represent the oldest rocks of the area.

The area where the granitic and tonalitic gneisses are better represented is around Pegasus Lake (south-central portion of map No. 1) and numerous geological traverses have been carried out from Dramnitzke Bay to Higginson Lake in order to understand the relationship between these quartz-feldspathic (=granitic) rocks and the adjacent units.

This large tongue-like body of granitic and tonalitic gneiss, foliated and plagioclase-rich is flanked on both sides by a metasedimentary belt which is quite continuous and regular. The whole complex is striking east-northeast, and dipping 50° - 70° to the south-southeast, except for the southwestern portion, between the west end of Dramnitzke Bay and Bell Lake, where the foliation varies from a northeasterly strike, to a north-northwesterly and finally to an east-west strike, between Bell Lake and Moose Lake.

Four geological cross-sections have been made; in the Chestnut Lake Area (A-A'), toward the west end of Dramnitzke Bay (B-B'), in the Bell Lake Area (C-C'), and in the Moose Lake Area (D-D').

The lithologic succession is, starting from the granitic gneiss (see Fig. No. 1):

A-A': 1) granitic and tonalitic gneiss, plagioclase-rich, foliated, with concordant amphibolite bands. 2) granodioritic granofels. 3) calc-silicate. 4) hornblende gneiss.

B-B': 1) granitic and tonalitic gneiss, plagioclase-rich, foliated, with concordant amphibolite bands. 2) granodioritic granofels. 3) migmatite. 4) granodioritic granofels. 5) calc-silicates. 6) hornblende gneiss. 7) biotite gneiss.

C-C': 1) foliated granitic and tonalitic gneiss. 2) granodioritic granofels. 3) migmatite. 4) granodioritic granofels. 5) migmatite. 6) granodioritic granofels. 7) migmatite. 8) calc-silicates. 9) hornblende gneiss. 10) granodioritic granofels. 11) biotite gneiss.

D-D': 1) foliated granitic and tonalitic gneiss. 2) migmatite. 3) granodioritic granofels. 4) calc-silicates. 5) biotite gneiss. 6) quartzite.

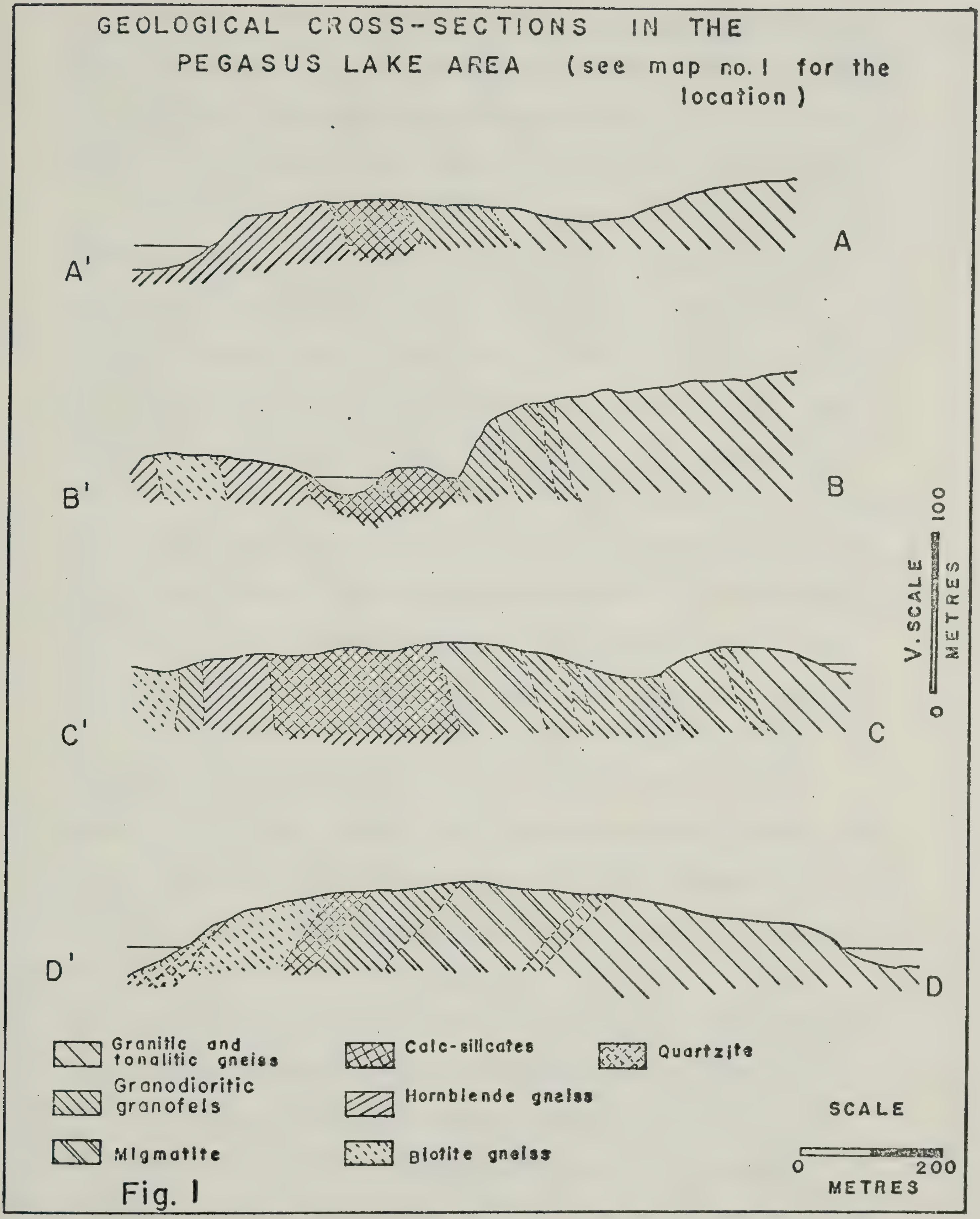

GEOLOGICAL CROSS-SECTIONS IN THE PEGASUS LAKE AREA (see map no. I for the location)
A'
A
B'
B
C'
C
D'
D
V. SCALE
0
100
METRES
Granitic and tonalitic gneiss
Granodioritic granofels
Migmatite
Calc-silicates
Hornblende gneiss
Biotite gneiss
Quartzite
SCALE
0
200
METRES

Fig. I

From the above presented data, it seems possible to draw a preliminary lithological sequence, namely: granitic and tonalitic gneiss-migmatite-granodioritic granofels-calc-silicates-hornblende gneiss-biotite gneiss-quartzite.

However, it is impossible to establish definitely the relative age of the units, on the basis of the above information. Furthermore other evidence is required in order to understand the geology of the entire area, since the lithological sequence found in the Pegasus Lake area might be incomplete and not sufficiently representative. Therefore a detailed geological mapping program was carried out in other portions of the Charlebois-Higginson Lake area, and in particular the area situated on the eastern shore of Charlebois Lake, approximately 2 km northwest of Fox Bay, will be presented in this paragraph (map. No. 1c, scale: 1:1,760). The granitic and tonalitic gneiss is there unfoliated and microcline-rich. A 30-50 metre thick horizon of biotite gneiss with incipient migmatization separates the granitic material from the true migmatite. Going west, granodioritic granofels is found and finally the calc-silicates on the shore of the lake. We could also extend the geological mapping of map No. 1c westward across Charlebois Lake and, according to the lithology found in the smaller and larger islands (see map No. 1) our ideal cross section through the lake will present hornblende gneiss in contact with the calc-silicates, then

biotite gneiss, hornblende gneiss and, on the opposite shore of Charlebois Lake, calc-silicates, granodioritic granofels and migmatite, and unfoliated granitic and tonalitic gneisses have been mapped again. All these units dip 40° - 80° to the east. This situation presents biotite gneiss in the centre of the ideal cross-section, and hornblende gneiss, calc-silicates, granodioritic granofels, migmatite, and granitic and tonalitic gneiss conformably present on both sides. Quartzite is missing. For the rest, all the other units have been identified in the four geological cross-sections examined earlier in this paragraph, except that the entire sequence is there inverted, the granitic and tonalitic gneisses being in the centre.

From the data discussed so far, the presence of a synform and of an antiform is evident. However the structural data do not give any valid criteria in order to distinguish between the two.

The solution of the problem comes from an area situated in the north part of Charlebois Lake, mapped at the scale of 1:9,000 (Fig. 2). There, structural data indicate the presence of a syncline without any doubt, and biotite gneiss is found in the centre, followed by hornblende gneiss, calc-silicates, granodioritic granofels, and granitic gneiss. Biotite gneiss is here evidently the youngest unit, while the granitic gneiss is the oldest one.

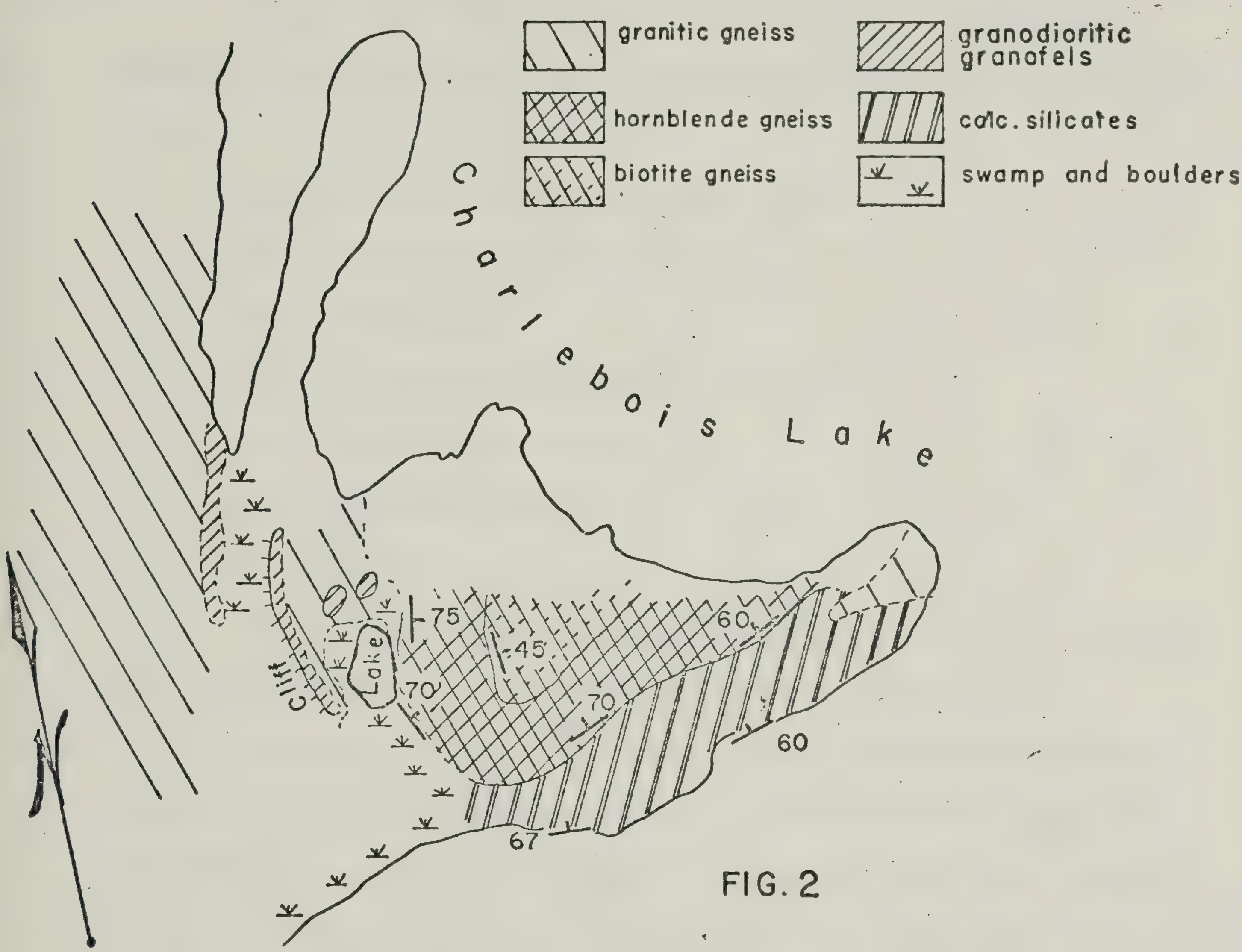


FIG. 2

GEOLOGY MAP OF THE
CAM - SHOWING

N. Charlebois Lake, N. Saskatchewan

SCALE 0 200 400 METRES

F. Morra — 1975

Consequently, the structural feature present in the Pegasus Lake area can be considered as an overturned antiform plunging steeply southwest, with the granitic gneiss representing the core.

Therefore, from the structural and stratigraphic evidence discussed so far, the stratigraphic sequence appears to be:

(a) Granitic and tonalitic gneiss

(b) Granodioritic granofels

(c) Migmatite

(d) Calc-silicate rocks

(e) Hornblende gneiss

(f) Biotite gneiss

(g) Quartzite

The metasedimentary assemblage (a) to (g) is termed the "Charlebois Lake Complex" in this thesis.

The position of the migmatite in the stratigraphic column is not completely clear: in some of the areas examined and mapped, it is found in contact with the granitic gneiss (e.g. map. No. 1c and map No. 1, areas south of Higginson Lake), but in most of the areas a continuous horizon of granodioritic granofels is in contact with the granitic gneiss, although this pegmatitic body is not often mappable at the scale we are using (1:16,000), being about 15 to 30 metres thick. It is possible to recognize a regular gradational contact between the granodioritic

granofels and the granitic gneiss all along the southern shore of Dramnitzke Bay down to Bell Lake. The north shore of Higginson Lake, from Moose Lake to Maxmen Lake, also presents the same lithologic feature (map No. 1).

Field observations and a detailed petrographic description of the individual units of the Charlebois Lake Complex are presented in the chapter on "Petrography" of this thesis.

To conclude the general description of the geology presented on map No. 1, we have to discuss the situation of the area immediately south of Higginson Lake.

A fault of regional extent, the Higginson Lake fault, striking approximately east-west, transects the area, and brings in disconformable contact different units of the Charlebois Lake Complex. The area south of this fault is largely composed of migmatite, granodioritic granofels, and granitic and tonalitic gneisses, whilst calc-silicate rocks, hornblende gneiss and amphibolite, biotite gneiss, and quartzite are only present in small amounts.

It should be noted that the granitic and tonalitic gneiss is mainly of the less foliated, microcline-rich variety in the southwest corner of map No. 1, in contrast to the foliated, plagioclase-rich variety found in the Pegasus Lake area. The variety typified by sample #26 would suggest that it forms the core of the overturned antiform around Dramnitzke Bay. However, the same variety

located by sample #'s 10 and 92 suggests the gneiss is in contact with the younger units of the metasedimentary sequence. As yet, this author has found no conclusive structural or genetic evidence to satisfactorily determine the exact relationship of the plagioclase-rich and the microcline-rich gneiss.

In a regional context, an attempt to correlate the lithologic units of this district with those recognized by Tremblay (1972) and Sassano (1972) in the Beaverlodge area has been made by Sassano (1974) in an unpublished report based upon very detailed field and laboratory studies performed by Sassano in the Beaverlodge area and upon a preliminary field interpretation of Mawdsley's (1957) and Cumming's (1952) geological sheets of the Charlebois Lake area. Sassano correlated the granitic gneiss of the area with the Donaldson Lake gneiss of the Beaverlodge area (of middle Tazin age). He also hypothesized that an unconformity separated the granitic gneiss from the Charlebois Lake Complex which was tentatively correlated with the Fay Mine Sequence (of upper Tazin age).

Only a geochronometric program performed on these rocks could definitely demonstrate whether this unconformity exists or not. On the basis of the stratigraphic and lithologic observation, this writer believes that the granitic and tonalitic gneisses are part of the Charlebois Lake Complex, but the problem is still open to further investigation.

The writer spent part of the 1975 summer geological season in the Tazin Group of the Beaverlodge area. Samples were collected and analyzed in the laboratory and the following conclusions arise when compared with the Charlebois Lake Complex:

a) All the units of the Tazin Group in the Beaverlodge district have been affected by a very strong post-crystalline deformation, with consequent formation of extensive mylonite, ultramylonite, and cataclastic zones.

b) This region formed part of a very active mobile zone where rocks of partly Archean age (Sassano et al, 1972) were sheared and crushed during the Hudsonian orogeny and are now polymetamorphic (Krupicka and Sassano, 1972, p. 430).

In contrast, the Charlebois Lake Complex does <u>not</u> contain mylonitic and polymetamorphic rocks, and few of the specimens examined (granodioritic granofels) show evident post-crystalline deformation (cataclasis). It is therefore very difficult to prove a correlation between the two areas with the data now available.

In the Beaverlodge area the Tazin Group is unconformably overlain by the Martin Formation.

Outcrops of a conglomerate similar to the Martin Formation were found on the northern shore of Black Lake, about 24 km south of Charlebois Lake. If the equivalence of this conglomerate with the Martin Formation can be

proven, the correlation between the Beaverlodge area and the Charlebois-Higginson Lake area will be easier to achieve.

Table I

Table of Stratigraphic Units

Recent and Pleistocene		Alluvium, lake silt and sand, gravel, eskers, glacial till.
		Major Unconformity
Helikian	ATHABASCA GROUP	Athabasca Formation (south of the mapped area).
		Unconformity?
		Martin Formation (west and possibly south of the mapped area).
		Major Unconformity
Aphebian		Pink pegmatite dykes and irregular bodies
		Intrusive contact
	CHARLEBOIS LAKE COMPLEX	Quartzite
		Biotite Gneiss
		Hornblende Gneiss and Amphibolite
		Calc-silicates
		Migmatite
		Granodioritic Granofels
		Granitic and Tonalitic Gneiss

CHAPTER III

PETROLOGY: Lithology of the Rock-types

1. Granitic and Tonalitic gneiss

a) Field Observations:

About two-thirds of the area is composed of granitic and tonalitic gneisses.These are especially well represented between Dramnitzke Bay and Higginson Lake, where they form the core of an overturned antiform, and between Charlebois Lake and Sprekley Lake. (map No. 1.).

This unit was previously mapped and described as being intrusive or an orthogneiss, and many geologists (e.g. J.B. Mawdsley, 1952, and L.P. Tremblay, 1968) made a distinction between the Tazin metasediments of this area and this "latter intrusive formation". They called it by different names (fine pegmatite, granite, pegmatite-granite, granite-gneiss, gneissic granite, banded granite-gneiss, massive granite, etc) (Mawdsley, 1952).

Undoubtedly there are igneous intrusions in the Charlebois Lake area, and they show evident and distinctive igneous textural features, but they are limited to the cross-cutting pegmatites and irregular pegmatitic bodies.

It is possible to subdivide the granitic gneiss through field observation on the basis of the degree of foliation present, or according to the K-feldspar content.

The geological mapping was made on the basis of the texture, whilst thin section mineralogical composition study was used for the lithologic classification.

Modal analyses of the specimens revealed a slight relationship between the K-feldspar content and the degree of foliation present: foliation generally increases when K-feldspar content decreases. (Table III). The foliation grades from well developed foliation, especially near the contacts, to slight foliation and is not evident when biotite makes up of less than 6 - 8% of the total rock volume.

The gneiss is pinkish in the more foliated type. The grain-size varies from fine (0.5 mm) to medium (1 mm). Coarse grained K-feldspar in lenses is often present, especially in the less foliated type; its segregation is likely due to metasomatic processes.

Amphibolite layers, two to three metres in thickness, are usually intercalated. They were noted to be especially prevalent near the contacts of the granitic gneiss and other units. (Plate IId and IIIc).

There is no sharp contact between the less foliated granitic gneiss and the more foliated one: there is rather a gradation from one to the other. Both types are concordant and each also shows a gradation into the adjacent granodioritic granofels and migmatite. (Fig. no. 3).

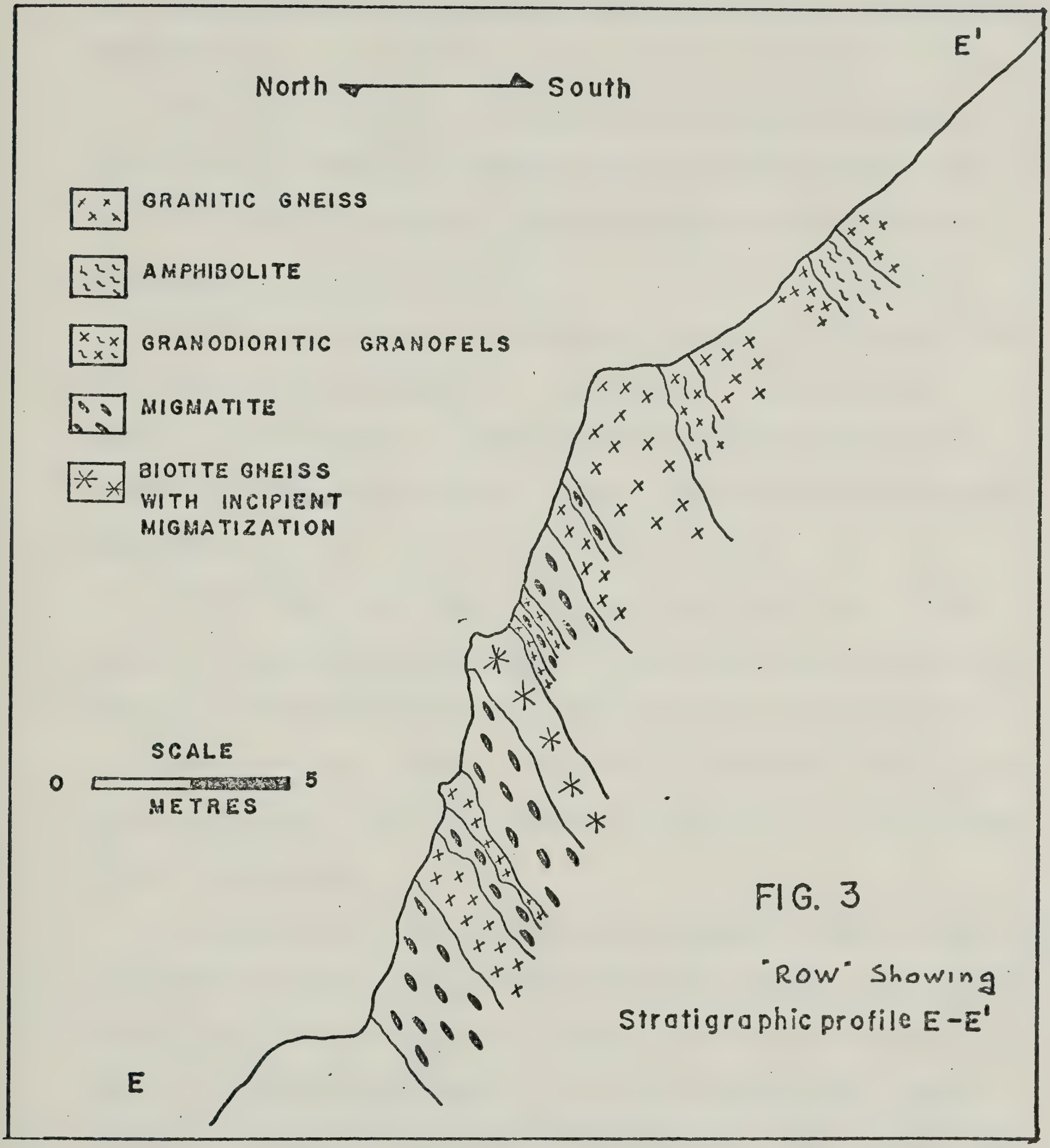


FIG. 3

'Row' Showing Stratigraphic profile E-E'

b) Thin section observations:

Petrographically, the granitic gneiss exhibits equigranular textures showing little or no post-crystalline deformation.

The rock consists of quartz, altered plagioclase (oligoclase-andesine), potash-feldspar (microcline), and biotite which is the most abundant ferro-magnesian component.

Quartz is present as irregular grains, sometimes with decussate grain boundaries. Undulatory extinction is always quite visible. Small blebs of quartz are often present in the plagioclase, as well as numerous myrmekitic intergrowths.

Plagioclase, mostly oligoclase, is found as anhedral grains, usually highly altered. Good cleavage planes and twinning are visible in some fresh grains, with myrmekitic intergrowths very common. Rounded plagioclase grains are often surrounded by microcline. Antiperthites are present in some specimens.

K-feldspar is found as coarse irregular grains showing excellent grid-twinning. The microcline grains are usually fresher than the oligoclase grains. The grain boundaries, when in contact with quartz, are often intricate, interlocking, curved or embayed. Perthites are very common and diffuse.

Biotite occurs as small, elongated flakes, usually segregated as separate individual grains. It is the only major mineral which is subhedral or euhedral. Pleochroism grades from pale brown to rusty brown. A slight foliation of the rock is visible whenever biotite is present in more than 5% of the rock-volume. Otherwise the orientation is not obvious. Biotite is often partly altered to chlorite, and often contains inclusions of apatite and metamict zircon, plus minor amounts of leucoxene, sagenite and other Ti-minerals.

Apatite, sphene, and metamict zircon are the most common accessory minerals. Chlorite, white mica and carbonates, sericite, and epidote are frequently found as secondary alteration products.

Modal analyses of some granitic and tonalitic gneisses are given in Table II.

Table II

Modal Analyses of

Granitic and Tonalitic Gneiss

Volume percentages of mineral constituents.

Number of counts per thin section (average): 1688.

Specimen #	10	19	20	23	26	57	58	92
Quartz	46	44	36	36	19	36	48	45
Plagioclase	29	52	50	34	10	28	36	23
K-feldspar	18	**		23	58	32	13	25
Biotite	5	3	11	7	13	3	2	6
Muscovite		*	**	*			1	
Sericite			*				*	
Chlorite	*	**	3	*	**		*	*
Epidote		*			*		*	*
Carbonates	*	*	*	**				1
Sphene	*	*	*		*	1		1
Apatite	*	*		*	*	*	*	
Zircon	*	*		*	*			
Fe-Ti-oxides	2	*		*	*	**		**

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%

Table III

Relationship existing between plagioclase/K-feldspar volume % ratio; K-feldspar/biotite volume % ratio; and foliation present in the granitic and tonalitic gneiss.

Specimen #	Plagioclase/ K-feldspar	K-feldspar/ Biotite	Foliation
7	0.57	3.5	None
10	1.61	3.6	*
15	1.52	3.28	None
19	52.00	0.33	@
20	50.00	0.00	*
23	1.47	3.28	@
26	0.17	4.46	@
57	0.87	10.66	None
58	2.76	6.5	*
92	0.92	4.16	None

@ Weakly foliated

* Very weakly foliated

None Foliation not ascertainable.

2. Granodioritic Granofels

a) Field Observations:

This unit was first termed "pegmatite-granite" by Mawdsley (1950, p. 9) and "younger intrusive fine pegmatite" by Cumming (1952, p. 6). This writer does not think that the term "pegmatite" can be used for this rock type because, by definition, a pegmatite is a rock having grain size of at least 2.8 cm and only two specimens from the 56 studied show this characteristic. Furthermore, the term "pegmatite" implies a genetic meaning which cannot be applied to our rock as suggested by field evidence and petrographic studies which will be discussed later in this paragraph. The term "granofels" seems the most compatible with the textural and mineralogical characteristic of this metamorphic rock. This term was first introduced by Goldsmith (1952) to indicate a "medium- to coarse-grained granoblastic metamorphic rock with little or no foliation or lineation" (in Glossary of Geology, American Geological Institute, 1972, p. 308). The term "granofels" does not imply that the rock was igneous or sedimentary before metamorphism, neither does it indicate any specific mineralogical composition, according to Bayly (1968).

This unit presents an average mineralogic composition equivalent to a granodiorite, varying widely from a diorite (e.g. sample #88), to a tonalite (sample #82), to a quartz-syenite (sample #63), and to an alkali-feldspar granite (sample #150). No relationship seems to exist between those

mineralogically different rock-types, although the rocks with a quartz-syenitic composition and those with an alkali-feldspar granitic composition are often spatially closely related to the granitic gneisses of the area. The granodioritic granofels is not easily distinguishable from the adjacent granitic gneiss on the basis of the mineralogical composition, whereas a distinction between the two units is immediate on the basis of their grain size (0.5 - 1 mm for the granitic gneiss, and 3 - 30 mm for the granodioritic granofels). In addition, foliation is present in the granitic gneiss, whilst the granodioritic granofels assumes a more massive habit.The granodioritic granofels borders the granitic and tonalitic gneiss as a continuous lenticular body for several km, being parallel to the regional foliation. It is possible to distinguish two main granodioritic granofels horizons, separated by a zone of "hybrid rock", or migmatite, which is 15 to 90 metres thick. The granodioritic granofels horizon closer to the margin of the granitic gneiss has a true thickness of about 30 metres, whilst the second one has a thickness of about 90 metres. This succession is particularly well exposed all along Dramnitzke Bay on the southern shore of Charlebois Lake. From the west end of the bay, going south to the west end of Higginson Lake, the relationship between the granodioritic granofels and the migmatite becomes more confused, with a greater amount of migmatitic

material, often rich in garnet and magnetite. The contact of the granodioritic granofels with the granitic gneiss is very gradational, the grain size becoming finer and the biotite assuming a sub-parallel orientation, as one approaches the granitic gneiss. The granodioritic granofels does not demonstrate a cross-cutting (or intrusive) relationship with the adjacent units anywhere in the area. Its parallelism with the topographically higher granitic gneiss and the lower calc-silicates is constant and continuous. The grain size varies from medium (3 mm) to coarse (30 mm). The colour is from light grey to white, but it changes to dark grey where biotite is very abundant and smoky quartz is present as a major component. In places, the colour is spotted pinkish, due to abundant coarse K-feldspar grains present. Quartz veins and pockets, up to 150 cm in thickness are often present in the granodioritic granofels. A 90 - 120 cm apatite rich (2 %) band is characteristic of the stratigraphically lower parts of the granodioritic granofels,close to the granitic gneiss contact and it is an excellent marker-horizon,especially south of Dramnitzke Bay,from Souter River to Bell Lake.The apatite grains are very well developed, dark-green and up to 5 mm in diameter. They show a perfect crystalline form, and are pure and translucent.

Specimen #32 is representative of a very uncommon type of granodioritic granofels present in the area. It is supposedly the result of an eutectic crystallization of plagioclase and quartz with a distinctive graphic texture showing elongated quartz grains. This specimen does not show any evidence of post-crystalline deformation or recrystallization of the minerals, therefore the columnar shape of the quartz grains may be due to a slow, but continuous unidirectional movement of the fluid while it was crystallizing.

b) Thin Section Observations:

The granodioritic granofels has an allotriomorphic granular texture. The grain size averages 5 mm in diameter, within limits of 3 mm to 30 mm. The mineralogic composition is primarily quartz, plagioclase, K-feldspar, and biotite.

Quartz, microscopically, is clear or smoky. In thin section, the grains are coarse, irregular, and fractured, with a strong undulatory extinction. Quartz is also present as small rounded blebs in or partly overlapping the plagioclase. Growth mosaic subtextures are often present. Some of the specimens show an evident cataclasis with crushed, granulated, and partly or completely recrystallized quartz. The mechanical fragmentation of the grains is quite evident in specimen #'s 11 and 24. Quartz also appears to have been deformed in

curved streaks, affecting the biotite grains, that are stressed, elongated, and "pushed" into the grain boundaries of other minerals.

The plagioclase is mainly oligoclase, with large variation in grain size. The grains are subhedral or anhedral, often with rounded edges, and the crystals are often surrounded by biotite, which is elongated and curved around the plagioclase grain boundaries. Alteration is present and often very diffuse. Antiperthites are present in some of the specimens. Myrmekitic textures are very common (Plate VIIc) and plagioclase is in part replaced by K-feldspar. The crystalline deformation affected the plagioclase very weakly. In specimen #11 bent lamellae are visible and they are also slightly broken and filled with new recrystallized quartz veinlets (Plate IVa).

The K-feldspar is entirely microcline, often occurring as coarse grains, irregular in shape, with good grid twinning. It is fresher than the plagioclase, which is intergrown with potash-feldspar. Inclusions of small rounded quartz grains as well as perthites are common. Sometimes as much as one-third of the individual crystal is composed of strings and patches of plagioclase. It was noted that the plagioclase grains are fresh when they are included in the K-feldspar grains whilst they are usually considerably altered when present at the borders.

Biotite, macroscopically, is present as small, very thin flakes or very coarse book-like aggregates up to 30 mm in diameter and 25 mm in thickness. Under the microscope it always shows to be randomly oriented. Biotite is segregated as separate grains or as aggregates of several intergrowths, usually with sharp borders and radiating edges. It varies from 2% to 35% of the rock volume (specimen #'s 47 and 99 respectively) and averages 8%.

Pleochroism varies from medium to rusty green and brown. When results of dynamic metamorphism (post crystalline deformation) are observed in the specimen, the biotite flakes are highly bent and broken (Plate IVc). Biotite is sometimes altered to chlorite (pennine) with the characteristic anomalous blue interference colour, radiating structure, and undulatory extinction (Plate VId). Metamict zircon, with pleochroic haloes around the grains (Plate VIId), is very common as inclusions in the biotite as well as apatite and sphene.

The most common accessory minerals are metamict zircon, apatite, sphene, and muscovite. Molybdenite, uraninite and secondary uranium minerals (carnotite, uranophane and possibly thucholite), pyrite, pyrrhotite, magnetite and rutile are sometimes present in lesser amounts. Secondary minerals consist of carbonates, sericite, epidote and chlorite.

Modal analyses of some granodioritic granofels are given in Table IV.

From field observations and from petrographic studies of the specimens under the microscope, the granodioritic granofels is considered to be endemic and a syngenetic part with the Charlebois Lake Complex.

Table IV

Modal Analyses of

Granodioritic Granofels

Volume percentage of mineral constituents.

Number of counts per thin section (average): 1636

Specimen #	4	24	29	47	63	82	94	150	154	155
Quartz	24	49	15	23	18	34	21	59	56	21
Plagioclase (oligoclase)	15	28	76	40	15	50	66	3	40	28
K-feldspar	41	10	2	35	50		3	38	2	41
Biotite	9	8	6	2	17	9	10	*	2	9
Muscovite		5			*	*				1
Sericite				*		**				
Chlorite	2			*	*	6	**			*
Carbonates	3	*	*	*				*		*
Epidote	1		*			**	*	*	*	
Sphene	3			*		*	*			
Apatite	1	**	1		*		*		*	
Zircon	1	*	*		*	*	*	*	*	*
Uraninite		*							*	**
Fe-Ti-oxides	*	*		*	**	*	*	*		*

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%

3. Migmatite

a) Field Observations:

What was previously called "injection gneiss" (Mawdsley, 1952 and Cumming, 1952) is in reality a "hybrid rock", or an exsudation migmatite,composed of a biotite-rich portion and separated lenses of granitic,granodioritic and tonalitic composition. For the generation of the migmatite, the old (injection) theory of an old mafic gneissic paleosome intermixed with younger intrusive leucocratic material (neosome) does not seem to be applicable to our rock-type. The stratigraphic position of the migmatite suggests rather that a gradual and cyclic, but definitely continuous change in the environment of deposition of the original sediments occurred. If we observe the geological sections (Fig. 1) made across the nose of the Pegasus Lake overturned antiform, starting from the granitic and tonalitic gneiss to the biotite gneiss we always find the migmatite in between and, in fact, its mineralogic composition is intermediate between the two rock-types: quartz-feldspathic bands (mineralogic composition equivalent to a granite); biotite-rich bands (equivalent to a biotite gneiss). In terms of original starting material we have had a deposition of arkosic-arenitic sediments and pelites. It is possible that the change in deposition was not sudden and definitive, but that a transitional period of pelitic and arkosic sedimentation, repeated in short, distinct cycles, took place. This gave rise to conformable and

regularly interbedded felsic (arkosic) and to mafic (pelitic) bands. (Plate IIa). This subject will be considered in detail later in the thesis (p. 72). Migration over small distances (few cm) of very mobile elements (such as K) took place, but it was not the primary mechanism for the formation of the rock. When the amount of leucocratic minerals is small, we find that these are restricted to small lenses and augen, typical of the biotite gneiss with incipient migmatization. The migmatite is well foliated and banded, and it is intimately associated, on both sides, with the granodioritic granofels.

The felsic intercalating bands are mainly composed of quartz, plagioclase and K-feldspar in various percentages. The mafic portions are biotite and/or hornblende-rich. They are well foliated, and the grain size is usually finer than in the felsic portion of the migmatite (0.5 mm and 4 mm respectively). Boudinage, drag-folding, kink-folding are common, especially in the southern section of the mapped area, where migmatite is abundantly represented (map. No. 1; Plate IIIa). Garnet-rich bands are present and can be used as marker horizons because of their continuity and constant position in the migmatite complex. Magnetite is also abundant, but its presence is rather patchy.

b) Thin Section Observations:

The migmatite possesses a granular, allotriomorphic texture. Quartz is present in different amounts, from a maximum of 74% (specimen #31 and #67)to a minimum of 13% (specimen #46) and averages 51%. The grains are usually coarse and irregular with embayed boundaries especially when they are in contact with plagioclase. Occasionally the grains are highly fractured. Undulatory extinction is strongly visible. Exceptionally, some of the migmatite specimens show cataclasis and quartz is partly or completely recrystallized. Fluidal textures, growth mosaic subtextures, and extremely fine crushed quartz grains are the typical results of this post-crystalline deformation. The very fine quartz grains usually border coarse K-feldspar grains or fill the fractures.

K-felspar, mostly microcline, varies from 48% of the rock-volume (specimen #98) to nil (specimen #31), averaging 13%. It is often present as porphyroblasts, with the grain size up to 20 mm in diameter. The grains are usually coarse, fractured, and irregular in shape. Grid twinning is very common. K-feldspar contains many inclusions of small, rounded plagioclase grains, highly altered and with a reaction rim around them. Perthites are common and show different shapes such as rods or strings. In some specimens, K-feldspar presents a strong undulatory extinction, and bent grains are common.

Plagioclase is of andesine-oligoclase composition. It varies from nil to 33% of the rock-volume. (specimen #67 and #59 respectively), averaging 13%. The grains are irregular, often altered, with numerous myrmekitic intergrowths. Zonation was noted in many of the specimens. Twinning is generally poorly represented. Plagioclase occasionally undergoes a partial replacement by the K-feldspar. Antiperthites were noted, but were not common.

Biotite is always present and its mode varies from 5% to 45% of the rock-volume (specimen #98 and 54 respectively), averaging 21%. It is present as separate grains or, more commonly, as aggregates of several intergrowths, with either a sub-parallel orientation or a random orientation of the grains. In some specimens, the sub-parallel biotite-rich bands give a marked gneissic texture to the rock. The grain size varies from medium (0.6 mm) to fine (0.2 mm). Pleochroism generally varies from medium brown to rusty brown. Numerous inclusions of metamict zircon are present in the biotite, with characteristic pleochroic haloes.

Accessory minerals are garnet and magnetite. In addition, the migmatite usually contains apatite, sphene, pyrite, Fe-oxides and metamict zircon. Less frequently sillimanite and molybdenite are found. As secondary minerals, epidote, carbonates and chlorite are the most common.

Modal analyses of some migmatites are given in Table V.

Table V

Modal Analyses of

Migmatite

Volume percentages of mineral constituents.

Number of counts per thin section (average): 1714.

Specimen #	9	31	40	46	54	59	67	89	98
Quartz	40	74	49	13	47	55	74	70	43
Plagioclase	29		12	31	5	33		6	4
K-feldspar	14		28	23				4	48
Biotite	17	25	11	31	45	11	26	20	5
Muscovite			*	*	**	*			
Chlorite	*					*		*	*
Sillimanite				*					
Carbonates	*			*		*			*
Epidote	*	1	*			*		*	*
Sphene				*	**	*	*	*	
Apatite		**	*	*	**		**		*
Fe-Ti-oxides		*	*		1	**	*		*
Zircon	*	*		*	**	*	*	*	
Molybdenite		*					*		

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%

4. Calc-silicate rocks

a) Field Observations:

In this unit we include amphibole-diopside gneiss, talc-serpentine-carbonate marble (ophicalcite) and sericite-phlogopite/biotite-diopside gneiss.

The calc-silicate horizon adjoins granodioritic granofels on one side, and the hornblende gneiss on the other side. It is a fairly continuous unit, of a considerable thickness (approximately 400 metres), striking for several miles, and parallel to the general foliation. It is present on both the shores of Charlebois Lake, Sprekley Lake, and Dramnitzke Bay. Evidently the presence of these calc-silicates also under the lakes indicates they have been gouged out by the glaciers as they are more easily erodable and subject to weathering than the gneisses. In the Higginson Lake area the situation is more complicated and not completely clear. There, this unit appears as discontinuous lenses and thin intercalations contained in an abundant migmatitic material.

(i) Amphibole-diopside gneiss: grain size varies from very fine to medium (0.2 mm and 0.6 mm respectively). The rock is generally massive and the colour is pale grey-green. This type is usually present near the contact with the hornblende gneiss. Olive-green tremolite crystals or grey-green radiating crystals of actinolite are visible on many outcrops. One specimen(#76) is wholly formed by

one crystal of diopside with some tremolite present in it. The main constituents are diopside, carbonate, hornblende, tremolite, sericite and plagioclase.

(ii) Ophicalcite: this rock is massive, dirty-white in colour, and medium to fine grained (the average grain size is 0.7 mm in diameter). In specimen #85 there is parallel orientation of talc, which is not microscopically ascertainable. The main components are carbonates, diopside, talc and serpentine (after forsterite) (Plate IVd).

(iii) Sericite-phlogopite/biotite diopside gneiss: this type is present as intercalated bands in the ophicalcite and in the amphibole-diopside gneiss (Plate Ia). This rock is fine-grained, with diopside and phlogopite or biotite grains less than 1 mm in diameter, and a groundmass of very fine sericite grains. The colour is from medium green-grey to dark green. Foliation is barely evident. Banding is strong with alternating bands (1 - 3 cm thick) of sericite-diopsidic material intercalating in a biotite gneiss type of rock. The main components are: diopside, phlogopite, sericite, biotite, microcline and plagioclase.

b) Thin Section Observations:

Microscopically, the calc-silicates present the following textural and mineralogic features:

(i) parallel orientation of the minerals is only

ascertainable in those specimens with a high content of talc, tremolite and sericite.

(ii) Phlogopite, biotite and talc generally show euhedral or subhedral grain development. Diopside, carbonate, and the other main constituents are anhedral.

(iii) most of the specimens show a mosaic texture, but some porphyroblastic texture was also observed (e.g. specimen #76).

(iv) post-crystalline deformation is usually absent.

Minerals:

Quartz is present in specimen #5, forming 5% of the rock-volume. The grains are round and equidimensional and often present as inclusions in the K-feldspar and in the diopside.

Plagioclase is more calcic than in the other groups, the anorthite content averaging 40%. The grains are usually small equidimensional and rounded. Twinning is not well developed. Saussuritization and sericitization of the plagioclase are common. Undulatory extinction is sometimes present.

K-feldspar-microcline is present in specimen #5 and it makes 18% of the total volume. The grains are irregular, showing frequent grid twinning and numerous perthites.

Biotite is present only in specimen #5 on one side of the thin section. It is very fine-grained (0.2 mm in diameter), subhedral and oriented in random positions showing almost a subparallel orientation. Pleochroism is pale brown to medium brown.

Phlogopite was found in specimen #2 and totals 40% of the rock. It is present in aggregates of several euhedral intergrowths segregated in parallel bands. The grains are sometimes slightly bent. Pleochroism varies from very pale brown to medium-pale brown.

Muscovite is present as very small grains, in a sericitic groundmass.

Amphibole is a very common mineral in this unit and it is especially represented by hornblende, which is often associated with diopside. The hornblende is pleochroic, from pale green to emerald green. Grains are usually small and subhedral. Coarser grains show poikiloblastic textures.

Cummingtonite is probably present in specimen #68. The pleochroism is very weak, from pale yellow to pale brown and the grains exhibit strongly embayed boundaries. It is optically positive. Tremolite is present as an alteration product of hornblende. It is often fibrous or in elongated grains, associated in aggregates with a sub-parallel orientation. Pleochroism is virtually absent. Actinolite is sometimes found as small rods or elongated grains in the diopside. Pleochroism varies from colorless to pale green.

Diopside: The concentration is variable, from nil to 79% of the total rock-volume (specimen #'s 14 and 76 respectively). It is present as small rounded equidimensional grains or as huge crystals up to 14 cm in length (rock sample #f-76). The grains are highly fractured and partly altered to uralite. Coarser grains have

embayed boundaries, poikiloblastic textures, and often contain inclusions of actinolite and/or tremolite. Some particularly large grains show twinning (specimen #2). Pleochroism is absent.

Serpentine is one of the major constituents in the ophicalcite (Plate IVd). The grains are usually well rounded and are present as separate crystals. It is pseudomorphic after forsterite.

Talc is present in two of the specimens studies (#85 and #14). Its total rock-volume is 17% and 10% respectively. Talc flakes are usually small separated and euhedral, showing parallel orientation. It is biaxial negative and optic angle is = 10^{o}-.

Carbonate: It is mainly dolomite, with possibly minor calcite. It makes up to 72% of the rock-volume (specimen #85). The grains are generally equidimensional poligonal or irregular, and show an excellent polysynthetic twinning. The distinction between dolomite and calcite has been made using staining techniques (Friedman, 1959).

The most common accessory minerals are sphene, apatite, Fe-oxides, and epidote. Graphite was found in specimen #68 and it is also possibly present in specimen #43.

Alteration minerals consist of serpentine, tremolite, sericite and minor amounts of uralite and saussurite.

Some modal analyses of the calc-silicates are presented in Table IV.

Table IV

Modal Analyses of
Calc-Silicate Rocks

Volume percentages of mineral constituents.
Number of point counts per thin section (average): 1529.

	Type A		Type B		Type C	
Specimen #	22	76	14	85	2	5
Quartz						5
Plagioclase	10	*		*	**	7
K-feldspar						18
Biotite						10
Phlogopite					40	
Sericite Muscovite	10				15	5
Hornblende	7					
Actinolite, Uralite						**
Tremolite		19				
Diopside	32	79		10	45	55
Epidote	1			*		
Serpentine			22	1		
Talc			10	17		
Carbonate	38	1	68	72		*
Saussurite	*					*
Sphene	2	1			*	*
Apatite			*		*	*
Fe-Ti-oxides			*	*		*

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%

5. Hornblende gneiss and Amphibolite.

a) Field observations:

This unit is closely associated with the biotite gneiss and occurs along a northeast-southwest trending belt, immediately north of Dramnitzke Bay. The hornblende gneiss contains a considerable amount of diopside at the contact with the calc-silicates, and of biotite at the contact with the biotite gneiss, so that an evident gradational character is present between this unit and the adjacent ones. The distinction between the hornblende gneiss and the amphibolite is made according to the foliation and the amphibole-plagioclase-quartz content of the rock; whenever foliation was absent and the amphibole was present in quantities more than 50%, with none or very little quartz, the rock was classified as amphibolite. Two specimens(#21 and #33) contain hornblende and diopside in almost the same volume-percentage and they should be better classified as pyribolites. As mentioned before, these represent an intermediate lithologic unit between the true hornblende gneiss and the calc-silicates. Pyribolites can hardly be considered mappable and they are included in the hornblende gneiss-amphibolite category.

The colour of the hornblende gneiss and amphibolite is from medium grey to dark grey depending upon the hornblende content which varies from 15% to 67% of the total rock-volume. The rocks of this group are fine or very fine-grained with the grains averaging less than 1/2 mm

in diameter. Sometimes an excellent alignment of the hornblende grains gives rise to a very good foliation of the rock (specimen #44, Plate IXa), but in most of the cases, hornblende grains are randomly oriented and the rock is rather massive.

b) Thin section observations:

The hornblende gneiss and amphibolite often have a mosaic texture or a subidiomorphic granular texture with subhedral hornblende. Post-crystalline deformation is absent.

Typical of this group is the absence of K-feldspar which was found only in two specimens of an amphibolitic band intercalated with the granitic gneiss (specimens #160 and #161).

The mineralogic composition is given by plagioclase and hornblende as main constituents while some of the specimens may contain biotite, diopside and quartz.

The quartz content is variable from nil to 13% (specimens #21 and #33 respectively). It is unstrained and free of inclusions. The grains are irregular, with smooth margins and are also seen as inclusions in the hornblende.

The plagioclase is commonly andesine-labradorite in composition and present in considerable amounts, sometimes making up more than 60% of the rock-volume. (e.g. specimen #28). The grains are small and very irregular with twinning poorly developed. Saussuritization is common. Antiperthites are locally developed.

K-feldspar is present only in specimen #'s 160 and 161, and in some specimens of antiperthites (e.g. specimen #21).

Biotite is present in small amounts in some specimens. The grains are small, isolated, and show a slight subparallel orientation or they are randomly oriented. Their pleochroism varies from pale brown to medium brown. Chloritization of the biotite is often common along the edges and the biotite cleavage planes. Some metamict zircon may be present as inclusions in the biotite. Biotite volume percentage varies from nil to 8% of the rock-volume (specimen #'s 28 and 30 respectively), averaging 2%.

Hornblende is usually present as aggregates of intergrown grains generally randomly oriented in the thin section. The grains are subhedral to anhedral with embayed boundaries. Coarser grains contain numerous small rounded quartz inclusions. Poikiloblastic structures of the grains are rather common. Pleochroism varies from straw yellow to emerald green or from pale green to deep-olive green. A few pleochroic haloes, with apatite grains (and metamict zircon?) in the center, are found in the hornblende. A very rare alteration to chlorite may be present. Hornblende can vary from 18% of the total rock-volume (specimen #28), to 67% (specimen #44), averaging 41%.

In specimen #28 a considerable amount of tremolite (4%) is present as fibrous, radiating needles, with undulatory extinction. It is evidently a product of alteration of the hornblende and also of pyroxene, probably due to starting retrogressive metamorphism. This specimen also shows a high content of sericite as an alteration product of the plagioclase.

Diopside is present in large amounts in a few specimens, either as small equidimensional round grains (specimen #37), or as coarse grains. Diopside is generally not pleochroic, but sometimes a very slight variation from colourless to pale yellow-green is seen (specimen #33). A high degree of fracturing of the grains is a common feature. Uralite is often present as an alteration product. Some actinolite is also found intimately associated with the diopside.

Accessory minerals consist of epidote and sphene with apatite, pyrite, and zircon.

Alteration is extensive especially in the plagioclase which is altered to sericite and carbonates, and in the biotite, which is altered to chlorite (var. penninite).

Modal analyses of some of the specimens of this group are shown in Table VII. The number of modal analyses presented for this group is limited because of the very fine grain-size of most of the specimens, which makes the point-counting method unsatisfactory for the purpose of this research.

Table VII

Modal Analyses of
Hornblende Gneiss and Amphibolite

Volume percentages of mineral constituents.

Number of counts per thin section (average): 1645.

Specimen #	21	28	30	33	44
Quartz		6	12	13	
Plagioclase	33	59	27	29	33
K-feldspar	**				
Biotite	3		8		
Muscovite Sericite	*	10		*	*
Chlorite	**	2	*	*	
Hornblende	34	18	53	37	67
Tremolite Actinolite		4			
Diopside	28			21	
Epidote	**	*		*	
Serpentine				*	
Carbonates	*	1			
Saussurite		*	*	*	
Sphene	**	*	*	*	**
Apatite		*	*	*	*
Zircon	*	*	*		
Pyrite	*	*	*	*	*

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%.

6. Biotite Gneiss

a) Field Observations:

It is mainly present along a belt striking NE-SW, situated between Charlebois Lake and Dramnitzke Bay, and on the north shore of Higginson Lake. It is intimately associated with the hornblende gneiss and, especially at the contact, it contains a high amount of hornblende. This unit is difficult to map because of the presence of numerous granodioritic granofels and hornblende gneiss intercalations. Therefore most of the area mapped as biotite gneiss may also contain hornblende as well as 3-6 metres thick granodioritic granofels bands.

The biotite gneiss is medium-dark grey in colour since the biotite content averages 20% of the rock-volume

The grain-size is fine to medium with the diameter of the grains averaging 0.5 mm.

Alignment of the biotite grains produces a strong foliation in the rock. Seven of the specimens studied showed a marked gneissic texture with segregation of the biotite in alternating bands, from half to one cm thick, separated by K-feldspar and quartz material. These samples were classified as "biotite gneiss in initial stage of migmatization" (Table VIII).

b) Thin Section Observations:

The biotite gneiss has a characteristic oriented texture with subhedral to euhedral biotite, subhedral to anhedral plagioclase, and irregular quartz grains.

Post-crystalline deformation is very slight or completely absent.

Quartz averages about 30% of the rock-volume. Specimens classified as "biotite gneiss with incipient migmatization" have a very wide range of quartz content, from 2% (specimen #17), to approximately 45% (specimen #50). The grains are up to 2 mm in diameter and are irregular, rounded or elongated, with embayed boundaries showing a moderate undulatory extinction. Coarser quartz grains are often elongated parallel to the foliation.

Plagioclase is usually andesine with minor oligoclase. It averages about 28% of the rock-volume, but in the "biotite gneiss with incipient migmatization" this value goes up to 46%. The andesine grains are usually subhedral, with some straight crystal faces, and are often equidimensional. Twinning is not very common, but when it occurs it is well developed. Myrmekitic textures are common in every specimen. Alteration is widespread especially along the cleavage planes.

K-feldspar (microcline) averages about 19% of the rock-volume, with some specimens showing no K-feldspar at all and others, especially those classified as "biotite gneiss with incipient migmatization" showing up to 40% of the rock-volume (e.g. specimen #64). The grains are usually fresh and irregular showing embayed boundaries when in contact with the quartz grains. Grid twinning is well developed. Perthites are common and present different

shapes (stringlets, rods, patches, beads). The plagioclase inclusions are often zoned showing a reaction rim.

Biotite occurs as aggregates of several subparallel intergrowths or as separate grains which are always elongated and oriented giving a good foliation to the rock. The grains are subhedral to euhedral. Pleochroism is from pale brown to medium-rusty brown. Numerous metamict zircon inclusions are found, with characteristic pleochroic haloes around the grains. Chloritization of the biotite is present in every specimen, and is common along the edges and the biotite cleavage planes.

Accessory minerals consist of metamict zircon, apatite, and muscovite. Sillimanite, sphene, pyrite and magnetite were found in some specimens. Garnet is present in large amounts in specimen #1 (Plate VIa).

Secondary minerals consist of epidote, carbonates, chlorite.

Modal analyses of some of the specimens of this group are presented in Table VIII and in Table IX.

Table VIII

Modal Analyses of

Biotite Gneiss

Volume percentages of mineral constituents.

Number of counts per thin section (average): 1761.

Specimen #	1	8	12	65
Quartz	29	28	43	29
Plagioclase	12	33	32	39
K-feldspar	16	29	15	16
Biotite	28	10	10	11
Muscovite	4	*		
Sillimanite	2			
Chlorite	1	*	*	*
Garnet	8			
Epidote	*	**		
Carbonates		*	*	*
Sphene		*		3
Apatite	*	**	*	2
Zircon	*	**	*	*
Pyrite				*
Magnetite-Hematite			**	1

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%.

Table IX

Modal Analyses of

Biotite Gneiss with Incipient Migmatization

Volume percentages of mineral constituents.

Number of counts per thin section (average): 1540.

Specimen #	17	38	64	79
Quartz	2	10	9	18
Plagioclase	62	32	28	62
K-feldspar	1	30	41	3
Biotite	33	28	22	17
Chlorite		**		
Carbonates	*	*	*	*
Epidote	*	*	*	*
Sphene	*	*	*	
Apatite	**	*	*	*
Zircon	**	*	*	*
Magnetite	2			*

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%.

7. Quartzite

a) Field Observations:

This lithology forms a small number of occurrences of mappable dimensions (south of Bell Lake and in between Higginson Lake and Moose Lake, map No. 1) and is more commonly found as unmappable beds or lenses within the area. According to its stratigraphic position in the two localities previously mentioned, it seems that the quartzite is the youngest member of the Charlebois Lake Complex, following conformably the biotite gneiss. This statement is subject to possible further modifications, since we cannot definitely establish the stratigraphic position of the quartzite on the basis of such limited information.

b) Thin Section Observations:

The quartzites are not "pure": quartz content averages 75%, the remaining portion being constituted by feldspars with minor amounts of biotite. No modal analyses have been made for this unit because the only sample of quartzite collected in the area would not have been representative for the purpose of this systematic research.

8. Pink Pegmatite Dykes and Irregular Bodies

a) Field Observations:

Coarse-grained pink pegmatite dykes and irregular bodies cross-cut all the other units in the area.

This unit is commonly present between Charlebois Lake and Sprekley Lake as extensive irregular bodies, and south-east of Charlebois Lake as dykes, 3-6 metres thick and therefore not mappable at the scale we were operating. It is also present, either as irregular bodies or as dykes in the Higginson Lake Area, a few hundred feet north of Guppy Lake.

Their colour is salmon-pink due to the great amount of pink microcline. The grain-size is coarse to very coarse with individual crystals up to one decimeter in length.

b) Thin Section Observations:

The mineralogic composition consists of abundant microcline, quartz, plagioclase, biotite, muscovite. Microcline forms up to 81% of the total rock-volume, as very coarse grains.

Quartz shows the same characteristics as in the granodioritic granofels. The grains are very irregular showing a strong undulatory extinction.

Plagioclase is present only in small quantities mainly as fresh patches included in the K-feldspar or as subhedral grains surrounded by microcline showing some myrmekitic textures.

Biotite grains are very coarse aggregates of several intergrowths, oriented in random positions. The edges of the grains are usually ragged. Muscovite may be present along the boundaries. Alteration to chlorite is

common, sometimes as radial aggregates of pennine. Pleochroism is from pale brown to rusty brown. The grains are slightly bent and fractured with the fractures filled by quartz.

The accessory minerals consist of chlorite, muscovite; black tourmaline was identified in large amounts in specimen #'s 100 and 230.

Preferred orientation of the minerals is not ascertainable.

Post-crystalline deformation is evident.

Modal analyses of some specimens are given in Table X.

Table X

Modal Analyses of

Pink Pegmatite Dykes and Irregular Bodies

Volume percentages of mineral constituents.

Specimen #	13	100	230
Quartz	5	33	35
Plagioclase	3	55	
K-feldspar	81	1	49
Biotite	10	**	2
Muscovite	**		**
Chlorite	1	*	
Tourmaline		11	14
Carbonates		*	
Epidote		*	
Fe-Ti-oxides	**	*	

* Mineral present is less than 0.5%

** Mineral present is between 0.5% and 1.0%

Metamorphism

The available petrographic data indicate that all the rocks of the Charlebois Lake area, except the cross-cutting pegmatites have experienced regional metamorphism. This conclusion is also supported by the fact that a large adjacent area of northern Saskatchewan is underlain by similar regionally metamorphosed rocks.

According to A. Spry (1969, p. 260), the most prominent microscopic feature in regional metamorphism is a foliation. In the Charlebois Lake Complex, biotite often shows a parallel and subparallel orientation and to a lesser extent hornblende and talc show the same foliation characteristics. This gives rise to a generally good foliation of the rock. Foliation is parallel to the original bedding, which is still well preserved in some of the units (Plate Id). Layering may be due in part to metamorphic differentiation, but more often corresponds to the original bedding.

As can be seen in the list of the specimens studied, presented in Appendix 1 and from modal analyses (Tables II to X), quartz, plagioclase, microcline, biotite and hornblende predominate in most of the various rock-types. Associated with these main constituents are other minerals as garnet,muscovite,epidote,chlorite and sillimanite.

Some of the most common mineral assemblages of the Charlebois Lake Complex are presented in Table XI.

In spite of its abundance, biotite can hardly be used to define metamorphic isograds. The occurrence of biotite is very much influenced by the composition of the original rock and therefore it cannot be used as a true indicator mineral. In general, biotite does not occur in retrograde metamorphic rocks, where chlorite is typical instead. The occurrence of chlorite in some of the specimens studied is undoubtedly as an alteration product from biotite, sometimes generated as a consequence of the cataclastic deformation of the rock followed by a weak retrograde metamorphism. Chlorite is thus pseudomorphic after biotite.

The presence of green hornblende associated with plagioclase was used by Wenk and Keller (1969) as a tentative subdivision of the amphibolite facies of mafic rocks into "zones", on the basis of the An content of the plagioclase in the amphibolites. According to these authors the An content of the plagioclase in the amphibolites increases with increasing temperature of metamorphism. This classification is not applicable to our situation, because of the presence of mineralogically different rock-types within the Charlebois Lake Complex: the Ca-content of plagioclase is more dependent on the original Ca-content of the rock than on temperature of metamorphism (e.g. the calc-silicates, in low-grade

Table XI

Typical Metamorphic Mineral Assemblages from the Charlebois Lake Area

Mineral Assemblage	Specimen #
Quartz-oligoclase-microcline-biotite-chlorite	215
Quartz-oligoclase-microcline-biotite muscovite	78
Quartz-andesine-biotite-hornblende	43A
Quartz-andesine-microcline-biotite sillimanite	80
Quartz-oligoclase-microcline-muscovite biotite-sillimanite-garnet	1
Quartz-andesine-hornblende-diopside	33
Sericite-diopside-actinolite-hornblende	37
Carbonate-talc-serpentine	85

metamorphism may contain labradorite, which is considered by Wenk and Keller (1969) as indicative of the upper zone of the amphibolite facies).

However, the presence of hornblende associated with plagioclase and diopside is in general indicative of higher grade metamorphic conditions. The occurrence of other amphiboles in some of the rocks of the Charlebois Lake Complex, indicative of lower metamorphic conditions, such as tremolite and/or actinolite, is considered to be essentially due to alteration processes.

The presence of muscovite in trace amounts is not indicative in terms of the conditions of metamorphism which affected these rocks, because of the large range of metamorphic conditions where the mineral assemblage containing muscovite can be generated.

The presence of sillimanite is much more indicative of high-grade metamorphism. A limited number of specimens contain sillimanite associated with biotite, plagioclase, and microcline. This paragenesis is described in Winkler's "sillimanite-almandine-orthoclase" subfacies of the amphibolite facies (Winkler, 1967), although garnet is expected to be present. In reality, garnet (var. almandine) was only sporadically found in the rocks of the Charlebois Lake Complex associated with sillimanite (e.g. specimen #1). This garnet deficiency can be explained if we assume an initial chemical composition high in potash and H_2O. The formation of garnet could

have been inhibited, and biotite was formed instead, with potassium feldspar associated.

The calc-silicates, too, are of interest in the interpretation of the metamorphic conditions of the Charlebois Lake Complex although rocks rich in calcium are generally less sensitive to varying metamorphic conditions than the rocks richer in aluminum and iron.

According to Barth (1952), Turner (1968), and Metz and Trommsdorff (1968), theoretical experiments regarding metamorphic transformations of siliceous dolomitic limestones show that the following minerals are formed in prograde metamorphism: talc, tremolite, diopside, forsterite, and periclase. The first three minerals have been found in the calc-silicates of the Charlebois Lake Complex. Periclase was not determined in any of the specimens studied, but brucite was recognized in specimen #14, intimately associated with serpentine, which is pseudomorphic after forsterite. Brucite is most likely secondary after periclase, which is rather unstable.

Talc forms first according to reaction.

(1) 3 dolomite + 4 quartz + $H_2O \leftrightarrow$ talc + 3 calcite + 3 CO_2
(Metz and Winkler, 1963).

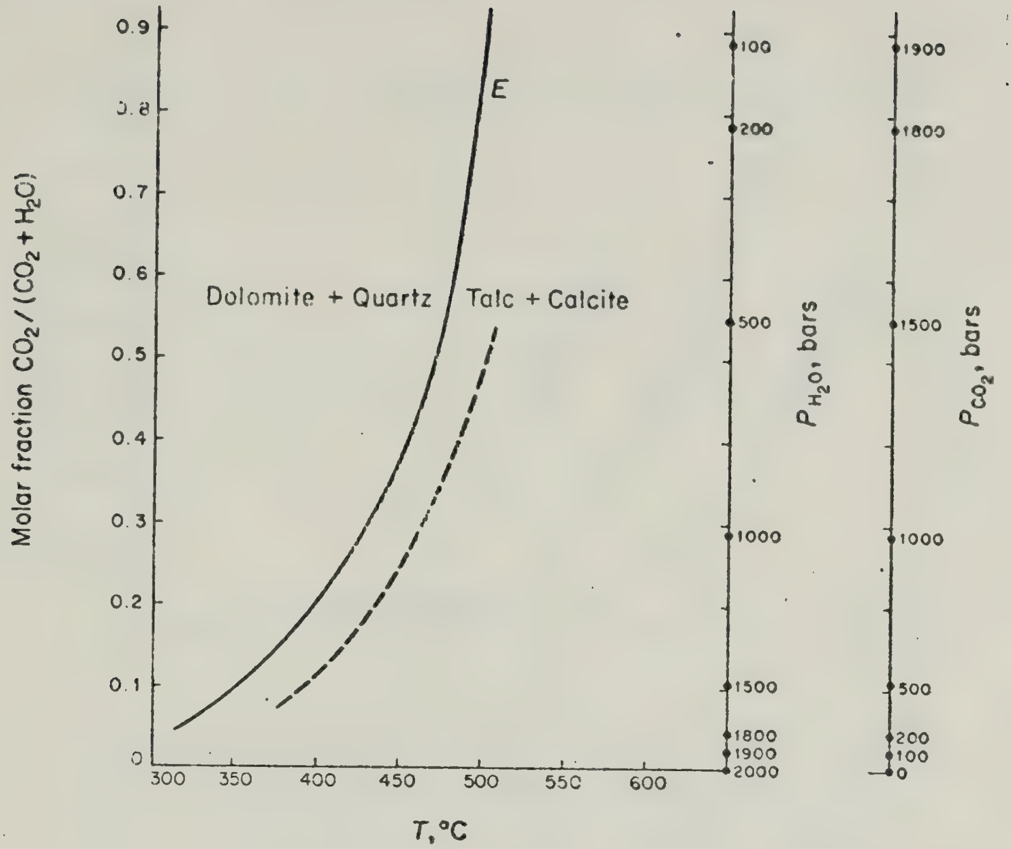


Fig. 4 . Experimentally determined curve (E) of breakdown of dolomite-quartz presence of CO_2 and H_2O, $P_f = 2$ kb.

(after P. Metz and H.G.F. Winkler, 1963).

Fig. No. 4 shows the experimentally determined curve (E) of breakdown of dolomite-quartz.

The broken curve is the equilibrium curve calculated from thermochemical data.

Talc may originate tremolite, according to reaction

(2) 2 talc + 3 calcite $\leftrightarrows$ tremolite + dolomite + H_2O + CO_2

(Metz and Winkler, 1963)

but, according to Turner (1968) tremolite can also be generated by the reaction between dolomite and quartz, at 180^oC and $P_{H2O} = P_{CO2} = 1$ bar (Fig. No. 5 curve N).

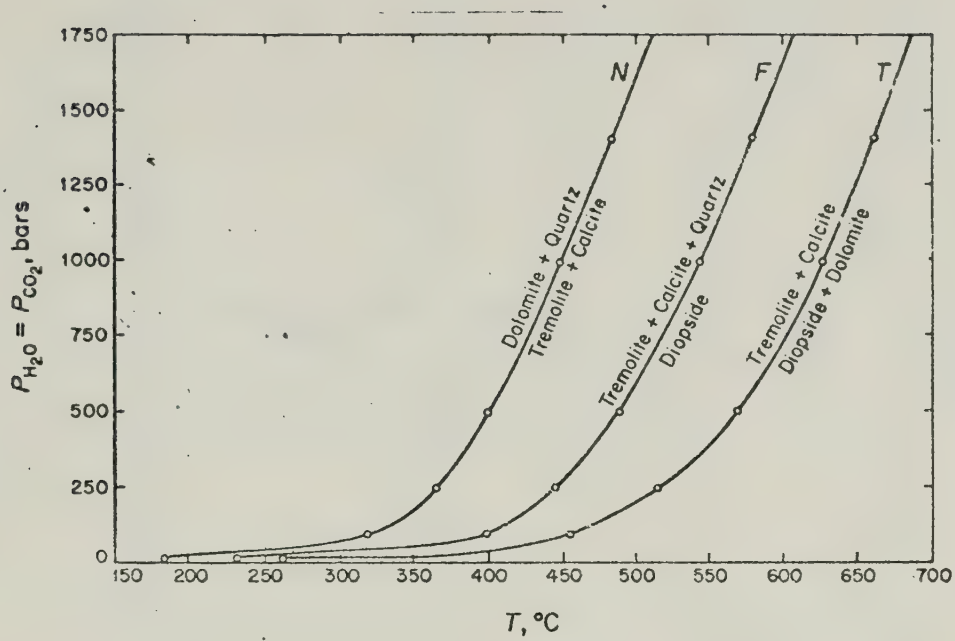


Fig. 5 Calculated curves of stable equilibrium for reactions in triangle Calcite-Dolomite-Quartz in presence of water. $P_{H_2O} = P_{CO_2}$. Tremolite is arbitrarily stated to be more stable than talc-calcite at temperatures to right of curve *N*. *N*: 5 Dolomite + 8 Quartz + $H_2O \rightleftharpoons$ Tremolite + 3 Calcite + $7CO_2$. *F*: Tremolite + 3 Calcite + 2 Quartz $\rightleftharpoons$ 5 Diopside + $3CO_2$ + H_2O. *T*: Tremolite + 3 Calcite $\rightleftharpoons$ Dolomite + 4 Diopside + CO_2 + H_2O.

(after Turner, 1968)

The appearance of these hydrous minerals (talc and/or tremolite) is followed by the formation of diopside, by the reaction

(3) tremolite + 3 calcite + 2 quartz $\rightleftharpoons$ 5 diopside + 3 CO_2+H_2O

Fig. No. 6 shows the experimentally determined curve (F) of univariant equilibrium, where X is an equilibrium point calculated from thermochemical data. Tremolite does not completely disappear by this reaction since it is associated with diopside in some of the specimens studied.

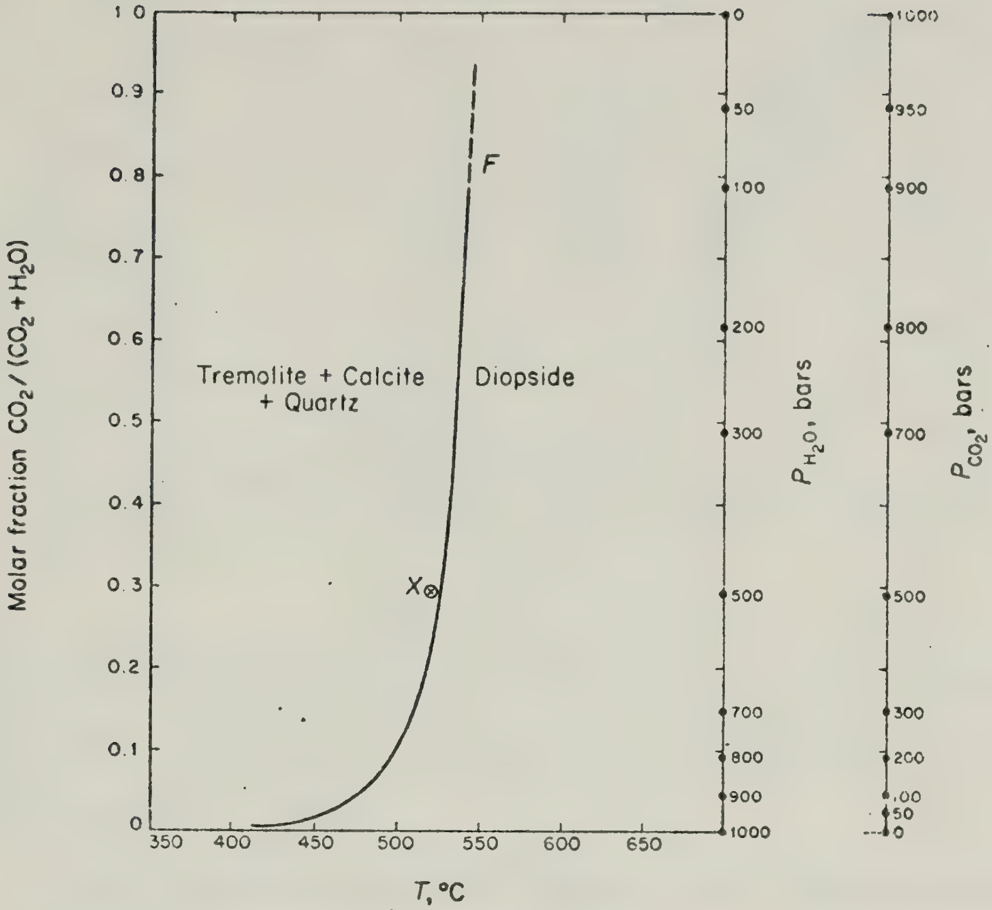


Fig. No. 6

Experimentally determined curve of univariant equilibrium for reaction No. (3). (After P. Metz and H.G.F. Winkler, 1963).

Forsterite may result from the reaction:

(4) Diopside + 3 dolomite $\rightleftharpoons$ 4 calcite + 2 forsterite + $2CO_2$

(Fig. No. 7, curve L)

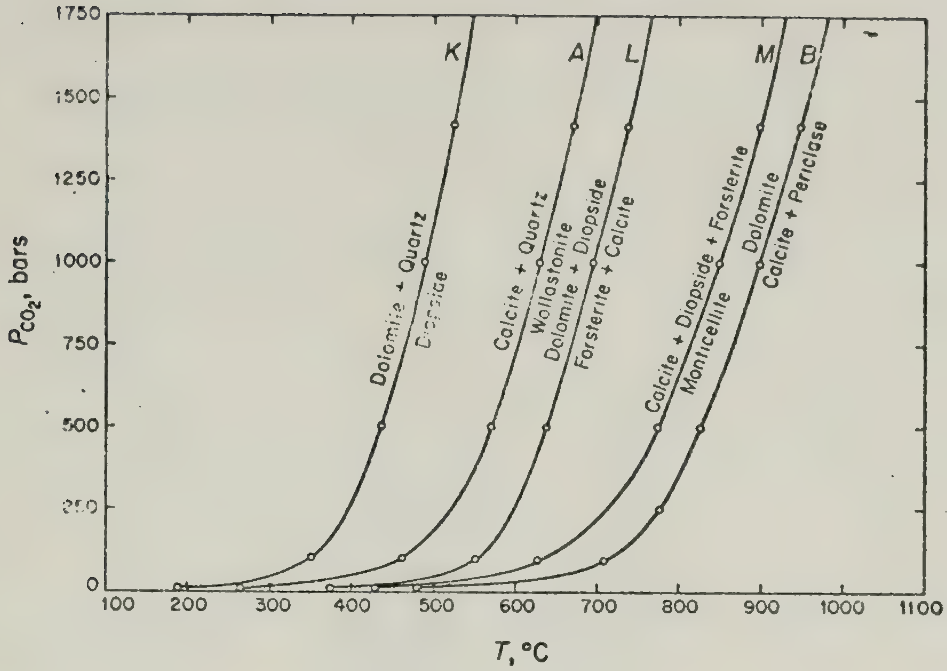


Fig. No. 7

Calculated curves of stable univariant equilibrium for reactions in triangle Calcite-Dolomite-Quartz; water absent (after Turner, 1968).

After forsterite was formed, the temperature must have been reduced below the equilibrium temperature, where it remained at some more moderate values until all forsterite was replaced by serpentine (curve 2k/2b in Fig. No. 8).

Brucite could also have been generated by alteration of forsterite, according to reaction.

(5) forsterite + vapour $\rightleftharpoons$ brucite + serpentine

(curve 1k/1b in Fig. 8), which is in equilibrium at about 425°C, according to Bowen and Tuttle, 1949.

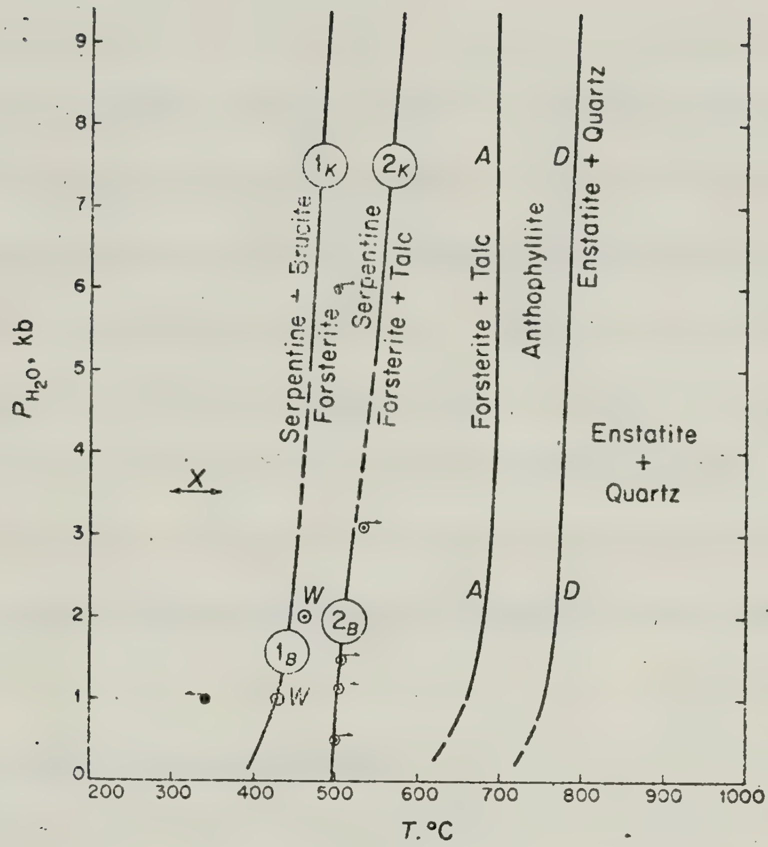


Fig. No. 8

Equilibrium curves determined experimentally for hydrous and anhydrous magnesian mineral phases. (After Turner, 1968).

The above stated data for different rock types lead to the conclusion that the maximum metamorphic temperature in the Charlebois Lake Complex was of the order of 600°C. This temperature is within the range of the amphibolite facies.

A somewhat more accurate identification of the metamorphic conditions (subfacies) is not possible on the basis of the available data, since chemical analyses of the samples would be required. The data indicate intermediate amphibolite facies metamorphic conditions and possibly also upper amphibolite facies conditions, the last suggested by the mineral assemblages containing sillimanite, and those originally containing forsterite.

Retrograde Metamorphism

Retrograde metamorphism is not very common within the rocks of the Charlebois Lake Complex.

Lower-temperature products are mostly represented by sericite (from plagioclase), tremolite (from hornblende and diopside), uralite, chlorite (from biotite), and serpentine (from forsterite).

In most cases, this transformation has a limited extent and affects only the edges and the cleavage planes of the primary minerals. Alteration minerals are always present in a metamorphic rock; they are produced by the decreasing temperature that follows every metamorphic phase

(regional or thermal). Therefore it does not seem appropriate to talk about larger-scale retrograde metamorphism in our case.

The petrographic description of the specimens indicates that in some cases the alteration is fairly widespread (e.g. specimen #'s 4, 22, 82, etc). In these specimens a large portion of plagioclase is replaced by carbonate and biotite is highly altered to chlorite. In this case we can say that a starting retrogressive metamorphism is present.

According to the petrographic study of the Charlebois Lake Complex, incipient retrogressive metamorphism is more evident in the calc-silicates where forsterite is completely replaced by serpentine (specimen #14), plagioclase is 50% replaced by sericite (specimen #22) and diopside is partly replaced by actinolite and uralite (specimen #5).

In conclusion, incipient retrogressive metamorphism appears to be only locally of quantitative importance within the Charlebois Lake Complex, although rarely completely absent.

Migration

In the Charlebois Lake Complex there is possible evidence of K-migration mainly in the migmatites. Modal analyses of the specimens and field observations indicate the presence of abundant microcline, often as large,

fresh, mostly unaltered porphyroblasts: this suggests some migration of K has taken place.

It seems probable that a high amount of potassium (in arkoses, e.g. already in the form of K-feldspar) was already present in the original premetamorphosed rock (and this is quite normal) and the migration of potash took place within the rock itself, for relatively short distances. This is common in metamorphic differentiation and initial migmatization. The result of this process is well visible in some portions of the Complex and, in particular, the migmatite member (Plates IIa and IIIb).

<u>Metamorphism: Conclusions</u>

(1) The Charlebois Lake Complex is essentially monometamorphic. There have been no rocks found bearing evidence of doubtless polymetamorphism.

(2) The mineralogical assemblage indicates that all the rocks belonging to the Charlebois Lake Complex have undergone regional metamorphism in the amphibolite facies. Assemblages belonging to the upper limit of the amphibolite facies are probably present, but the corresponding samples are too few and too scattered over different localities to enable more definite petrogenetic conclusions.

(3) The products of retrogressive metamorphism appear to be quantitatively insignificant, although not completely absent. A starting retogressive metamorphism was ascertained in some of the specimens, especially in the calc-silicates.

(4) Some short-distance K-migration took place. It is thought that potash migration is at least in part responsible for the formation of the migmatites.

<u>The Precursors of the Charlebois Lake Complex</u>

The actual thickness of the Charlebois Lake Complex is difficult to estimate because of the presence of overturned folding and also because the lower contact of the granitic and tonalitic gneisses is not visible in the mapped area. The whole complex is supposed to be not less than 2000 m and possibly 3000 m or more in thickness.

Field and petrographic evidence suggest that the pre-existing rocks were sediments possibly interbedded with some pyroclastic material.

The evidence is:

a) Pronounced structural concordance of the formations.
b) Frequent gradational character of contacts.
c) Strong foliation, regular banding, and fine lamination.
d) Continuity and regularity of the same lithologic sequences for several kilometres.
e) Presence of calc-silicates conformably intermixed as part of the metasedimentary sequence.

Furthermore, against the igneous theory for the emplacement of the granitic and tonalitic gneisses stand the following observations:

A) Field Observations:

a) Absence of dome-shaped forms.

b) The contacts with adjacent formations are always conformable, often gradational, and they never show thermal metamorphic aureoles.

c) Repetition of the same lithological sequence on both limbs of antiforms, where the granitic and tonalitic gneiss now forms the exposed core (map 1).

d) Presence of very continuous, concordant amphibolite bands, regularly intermixed with the gneiss, whose origin is very probably from pyroclastic deposits.

B) Thin Section Observation:

a) None of the specimens (except one, a granodioritic granofels) showed igneous textures.

Field and thin section evidence suggests the following conclusions about the premetamorphic rocks of the Complex and their environment of deposition:

a) The granitic and tonalitic gneisses were probably derived from arkosic arenites and arkosic wacke.

b) It is also likely that the mineralized granodioritic granofels present in the area is syngenetic. This

subject will be extensively discussed in the second part of this thesis with regard to the origin of the uraniferous deposits of the region.

c) The calc-silicates are derived from calcareous pelites, calcareous sandstones, arkose and graywacke.

d) The hornblende gneiss is believed to be derived from tuffites, the amphibolites from tuffaceous and pyroclastic rocks of basaltic composition.

e) The biotite gneiss and the metaster (paleosome) of the migmatites are probably derived from pelites.

f) The quartzite is not from pure quartz sandstone because of its high content in feldspar. The original material was very probably a feldspathic arenitic sediment, which is characteristic of a marine platform (shallow water conditions). But if quartzite is the upper member in the stratigraphic column of the Charlebois Lake Complex, as it was discussed in the general geology chapter, and was deposited immediately after the parent rocks of the biotite gneiss (pelitic sediments), we have to assume a period of crustal instability caused by epeirogenesis or starting orogenesis, and consequent marine retrogression.

Volcanism was rare. The only material which has a volcanic origin is the amphibolite and components of the hornblende gneiss. The volcanic origin is primarily supported by the fact that the amphibolite is present in layers several hundreds of meters long and a few meters or even centimeters thick, conformably interbedded within the granitic gneiss (map 1, immediately south of the western portion of Dramnitzke Bay and south of Chestnut Lake).

The environment of deposition of the original sediments is considered to have been marine, because of the presence of considerable thicknesses of pelitic material. The deposition also possibly took place in a proximal platform, probably subjected to periods of lagoon or deltaic depositions.

There could have been sudden and cyclic changes in depositional environment, evidenced by thin intercalations of calc-metasedimentary rocks, and also slow changes in the conditions of deposition, as evidenced by the very gradational contact between the hornblende gneiss and the biotite gneiss.

Table XII presents a tentative correlation between the original materials and their possibly precursors.

Table XII

Tentative correlation between the metasedimentary rocks of the Charlebois Lake Complex and their Possible Precursors.

Original lithology	Metamorphosed equivalent
Arkosic arenites and arkose wackes.	Granitic and tonalitic gneiss granodioritic granofels.
Tuffitic, tuffaceous and pyroclastic materials.	Hornblende gneiss and amphibolite.
Calcareous pelites, calcareous sandstones.	Calc-silicates.
Pelites.	Biotite gneiss.
Feldspathic arenites.	Quartzite.
Arkosic arenites and interbedded pelites.	Migmatite.

Petrology:Conclusions

The following conclusions may be made from the results of the field and laboratory studies:

(1) The great majority óf the rocks present in the Charlebois-Higginson Lake Area are metamorphic. Even the granodioritic granofels is endemic, syngenetic and forms integral part of the Charlebois Lake metasedimentary sequence.

(2) The Charlebois Lake Complex consists principally of metamorphosed supracrustals, metasediments and minor amounts of metavolcanics. Also most of the granitic and tonalitic gneisses present in the area are considered to be metamorphosed arenites and not orthogneisses.

(3) The absence of polymetamorphism indicates that the rocks in the area were metamorphosed only once.

(4) Regional metamorphism of the intermediate amphibolite facies is widely evidenced. Traces of higher metamorphic conditions within the amphibolite facies have also been found in the Complex.

(5) There is evidence of possible migration of potash, which may partly be responsible for the formation of the migmatite.

(6) The high number of metamict zircons and the occurrence of uraninite, especially abundant in the granodioritic granofels and migmatite members is somewhat unusual. The origin and economic potential of these occurrences are discussed in Chapter VI of this thesis.

CHAPTER IV

STRUCTURAL GEOLOGY

General

An excellent general view of a portion of northern Saskatchewan is given in Figure 9. Co-ordinates are shown at the margins and the Charlebois-Higginson Lake area is situated in the southern portion of the photo.

On the basis of this satellite picture, it was possible to delineate the general structural geologic features of the region (Fig. 9). According to Beck (1969, p. 28) the triangular area immediately northwest of Black Lake forms part of the Stony Rapids 'linear belt' and it is bounded by two regional faults which converge to the northeast. Portions of a "broad open" syncline which plunges gently southwest at 20° is visible at the southwest corner of Figure (Beck, 1969, p. 28). The trough of the fold is occupied by the Stony Rapids norite body.

The region is completely faulted and only the major faults are discussed here.

The Black Lake fault has a general northeast trend. Diamond drilling, in the proximity of Black Lake, has shown that this fault dips 65° - 70° northwest with basement gneisses in the hanging-wall and Athabasca sandstones in the footwall.

LEGEND

Thrust fault ....
Normal or tear fault ....
(showing dip and relative movement)
Topographic lineament ....
(fault or major joint)
Fold axis ....
Structural trend ....
'b' – lineation ....
Mylonite zone ....
Glacial striae ....
*Dark areas in the photograph represent burnt portions of the forest.

FIG. 9 – STRUCTURAL ELEMENTS of the STONY RAPIDS LINEAR BELT (modified after L.S.Beck, 1969)

0 15 30
Km

Byers (1962, pp. 40-59) has suggested that the Higginson Lake fault may be the eastern extension of the Clut Lakes fault. This involves a left-hand displacement of about 6.5 km along the Black Lake fault, which would explain the presence of Athabasca sandstones in the foot-wall of the fault. (Beck, 1969, p. 28).

The Clut Lakes fault dips 60° - 65° south. Colborne (1961) suggested a movement of the hanging-wall side up to the north and, in addition, Johnstone (1964) suggested a right-hand strike displacement of about 350 m.

The Grease River fault zone consists of a number of northeast-trending faults. Wall-rock structures indicate that the faults dip steeply north and have a right-hand reverse movement. The amount of movement is not known (Beck, 1969, p. 29).

Northwest-southeast compression has been considered by most geologists as the cause for the generation of the Grease River and Black Lake faults and also for the generation of the broad folds in the cover rocks north of Lake Athabasca. This compressional direction is also supported by the fact that most tension faults in the area trend north-northwest to northwest.

Charlebois-Higginson Lake Area:

Faults:

Very few, poorly exposed faults in the Charlebois Lake area have been reported by Mawdsley (1950, p. 19), because only few pronounced displacements of formational contacts due to cross faults were noted. All the major faults mapped in the area are parallel or sub-parallel to the regional foliation direction and to boundaries of map units within the Complex. They are thus difficult to recognize. However, as was pointed out by Mawdsley (1952, p. 372) sheeting (close jointing), talcose schist, and some breccia were found along physiographic depressions that, in themselves, suggest the presence of faults.

The most prominent lineament is represented by the already mentioned Higginson Lake fault (southwest corner of the map-area; map no. 1 and no. 2). This fault is marked by an irregular drift-filled depression and brings in contact, lithologically and stratigraphically, different types of rocks. Right-hand offset of the members of the Charlebois Lake Complex indicates right-hand strike separation. Offset is ascertainable on the basis of Mawdsley's (1957) and Johnstone's (1964) geological sheets and it ranges from 1000 m to 2000 m. Movement and offset coincide with those observed on the Clut Lakes fault (Johnstone, 1964) and which Byers (1962)

considered may be the same fault structure. Rocks along the Higginson Lake fault are often red-stained and biotite is highly chloritized. Minor cataclasis is also recognizable in this locality. Northeasterly trending minor faults and joints intersect the Higginson Lake fault and form precipitous cliffs and topographic depressions.

A suspected northeast-southwest striking fault passes through Dramnitzke Bay and its presence is suggested by the straight shore of the bay, especially well evidenced from aerial photographs. Several northeastern striking minor faults have been mapped adjacent to the Dramnitzke Bay fault: offsets, of the order of 100 - 300 m, indicate a left-hand strike separation.

A third east-west striking major lineament is present in the north section of the map-area, from Heisler Lake to Charlebois Lake and possibly extending to Sprekley Lake. This structural feature is also well prominent on aerial photographs. A mylonite zone and string shearing on the granitic gneiss occurring in the west shore of Sprekley Lake (Cumming, 1952) also suggest some movement. No offset of the adjacent unit has been observed, although it would have been quite difficult to recognize owing to the persistence of the same lithology on both sides of the fault, for its entire length.

Folds:

The attitude and distribution of the metamorphics of the Charlebois Lake Complex form a definite pattern (map no. 2), indicating the presence of a number of folds in which the granitic and tonalitic gneisses form the core of anticlinal structures and the other members of the Charlebois Lake Complex tend to occupy synclinal troughs.

The map-area can be divided into two domains, according to the general trend of the fold axis and the ideal dividing line may be drawn from the western end of Dramnitzke Bay to Chestnut Lake.

The north section is characterized by ill-defined, north-northeast trending structures, while the southern part of the area is mostly occupied by an antiform, whose axial trace trends approximately northeast-southwest.

North Section: the area between Sprekley Lake and Charlebois Lake is occupied by an isoclinal antiform associated with several other minor antiforms and synforms, with their axis trending north-northeast. Another major synform is present in this area and its axis follows the direction of the north section of Charlebois Lake. This synform, representing the key for the solution of the stratigraphic problem of this region, has already been largely discussed in Chapter II, pages 12-16.

South Section: the most prominent feature of the area is the so-called "Pegasus Lake antiform", the axial trace which extends from the southwest end of Dramnitzke Bay, through Pegasus Lake and Ott Lake. It is overturned to the north, and its western nose plunges to the southwest at 70^{o}. Both the north and the south limbs of this antiform are steeply dipping to the south at approximately 75^{o}. Several parasitic folds, well evidenced by the conformable amphibolite bands intercalated with the granitic and tonalitic gneiss, are visible in the nose of the Pegasus Lake antiform. (Plates IIb and IIIc). The second major fold of the southern section is situated between Higginson Lake and Guppy Lake, with its axis trending approximately east-west. It is a very complex structure, and not completely understood. The lack of data in the northern limb of this structure does not permit any certain interpretation. Stratigraphic data suggest the presence of an antiform, because the core of the structure is formed by granitic gneiss which has been recognized to be the oldest member of the Charlebois Lake Complex (map no. 1). The available structural data (map no. 2) suggest instead the presence of a synform. This apparent contradiction can only be solved by a greater amount of structural information and therefore, at present, any interpretation should be regarded as totally speculative.

Drag-folds are visible in the area between Guppy and Higginson Lakes. They are usually of a "Z" configuration, indicating that normal and reverse movements took place in the area at two separate times. Some, if not all of the major drag-folds are strictly related to major faults and dislocations (i.e. Higginson Lake fault).

CHAPTER V

GENERAL GEOLOGY OF THE URANIUM DEPOSITS

Generalities

The purpose of this chapter is to present a description of the manner and occurrence of the mineralization found within the Charlebois-Higginson Lake area, with the ultimate objective of determining its nature and origin.

The petrology of the uranium-bearing granodioritic granofels and migmatites present in this thesis area has been discussed in previous chapters. From the results of field and laboratory studies, these uranium-bearing rocks appear to be typically endemic, syngenetic, and form an integral part of the Charlebois Lake metasedimentary sequence.

Consequently, any further consideration of the genesis of the uranium mineralization found in the thesis area will be based upon the assumption that the uranium-bearing rocks of the Charlebois Lake Complex were originally associated with a sedimentary sequence.

History of Exploration and Development

In August, 1948, R. Tobey and J. Albrecht discovered pitchblende veins on the west shore of Black Lake close

to a north-easterly trending fault. Detailed prospecting and exploration disclosed an important deposit which was explored by NISTO Mines Ltd. This discovery aroused considerable interest and a number of concessions were obtained from the Saskatchewan Government on land north-east of the Nisto property. During the summer of 1949, the claims were actively prospected without significant results. By the late summer most of the prospectors had moved east and northeast, where a number of finds were made in various localities on the northeastern end of Black Lake, on Pluto Bay and on Charlebois Lake. Most of these radioactive anomalies were discovered by ground searches using geiger counters and scintillometers. Geological work was confined almost entirely to surface and near-surface exploration and numerous bodies containing low grade uranium occurrences were drilled and assayed.

During the summers of 1949, 1950 and 1951, the area surrounding Charlebois Lake was very actively investigated. Sampling, trenching and drilling was performed by the Consolidated Mining and Smelting Co. of Canada Ltd., Charlebois Lake Uranium Ltd., Dee Explorations Ltd., E. Partridge and Associates Ltd., Pinex Mines Ltd., and Arctic Yellowknife Mines Ltd.

Although several rich horizons were found, with assays of some grab samples showing up to 0.197% U_3O_8 on rocks rich in quartz and biotite (Arctic Yellowknife Mines Ltd. property, Dramnitzke Bay, 1951), the average grade of the reserve was too low to be of immediate economic interest.

Furthermore, at that time, no radioactive "pegmatite" deposits were known which could be worked profitably as a source of uraninite (Mawdsley, 1952, p. 366). As the Charlebois occurrences were generally believed to be of this type, they did not arouse wide general interest.

Very few geologists believed in the importance of this new type of uranium deposit, but one of them who did was J.B. Mawdsley who, in his report on "The Uraninite-Bearing Deposits in the Charlebois Lake Area" in 1952, wrote (Mawdsley, 1952, p. 367): "The North arm of Charlebois Lake lies along a belt of metamorphosed sediments flanked on both sides by large masses of granite. There are at least eight interesting radioactive bodies within a distance of six miles along the poorly exposed contacts between the sediments and the two granite masses". Furthermore, in the same report (Mawdsley, 1952, p. 367) the author points out the economic importance of the radioactive occurrences found in the Charlebois Lake area: "It seems quite evident that the

considerable work done during the past season (1951, n.d.r.) has confirmed the presence of radioactive material of ore grade at a number of localities within the area ... . Large tonnage of low, but commercial grade should be found in some of the numerous, long radioactive zones present in the district ....." This quote was made when the price of uranium was $8.00/lb.

The area was almost completely abandoned from 1953 until 1965, when Barringer Research Ltd., on behalf of Numac Oil and Gas Ltd., performed an intensive gamma-ray spectrometry survey over the Charlebois Lake area.

Additional work which included sampling, trenching, assaying and drilling was also performed in 1965-1966 by Pinex Mines Ltd., King Resources Ltd., Imperial Oil Enterprises Ltd., Essex Royalty Co. Ltd., Copper Range Exploration Co. Inc., Cominco Ltd., and others.

In 1974, Fosago Explorations Ltd. carried out an exploration program in the Charlebois-Higginson Lake area, consisting of detailed geological mapping and radiometric surveys in order to study the relative stratigraphic position of the radioactive occurrences. In addition,by diamond drilling, vertical control of the mineralization down to a depth of approximately 70 m was obtained in one of the main showings.

The Radiometric Survey and its Limitations

Airborne radioactive anomalies detected in the Charlebois-Higginson Lake area were ground checked in 1974 and in 1975 by Fosago Explorations Ltd. using S.R.A.T. SPP2 scintillometers.

Lack of rock exposures over many of the airborne anomalies was the chief obstacle to detailed radiometric mapping. Field experience showed that 7 cm of overburden would cut out approximately one-half of the radiation flux from a given source and that 30 cm of drift would almost completely eliminate all of the radiation. Consequently, radioactive bodies covered by more than 30 cm of drift could not be detected by the S.R.A.T. SPP2 scintillometer or by most of the other types of scintillometers. Thus, since most of the area involved is covered by varying depths of overburden, the radioactive bodies are not always accurately delineated by ground radiometric surveys. For this reason stripping of overburden and trenching were done at regular intervals, across the most interesting showings in the Charlebois Lake area. Readings were taken over the exposed rock surface and from these readings isorad maps on a scale of 1:1,760 were prepared for each radioactive zone. The detailed geological maps combined with corresponding isorad maps form a good guide for preliminary interpretation of the control of mineralization, besides furnishing good indications for the spotting of diamond

drill holes (e.g. map No. 1c).

Furthermore, it is noteworthy that correlation between radiometric readings obtained with the scintillometer, and subsequent assay values is not always satisfactory. Figure 10 presents some radiometric values, expressed in counts/second, obtained by S.R.A.T. SPP2 scintillometer detecting approximately 250 gm of rock-samples. These readings are compared with the corresponding U_3O_8% values obtained from wet chemical analyses. (Loring Laboratories, Calgary).

Distribution of Uranium Deposits

According to Beck's classification of uranium deposits in the Athabasca region (1969, p. 31), the Charlebois Lake deposits fall into the "lit-par-lit" type, consisting of "bands and lenses of pegmatite interlayered with metasedimentary rocks around the borders of well-defined granite stocks". This last statement is contrary to our previous petrographic conclusions. The combination of detailed geological and radiometric mapping presents evidence that the radioactive zone is always located between a band of more or less calcareous metasediments, the calc-silicates, and a generally foliated granitic gneiss. All important radioactive showings occur in the granodioritic granofels and in the migmatite, which are themselves both part of the metasedimentary sequence.

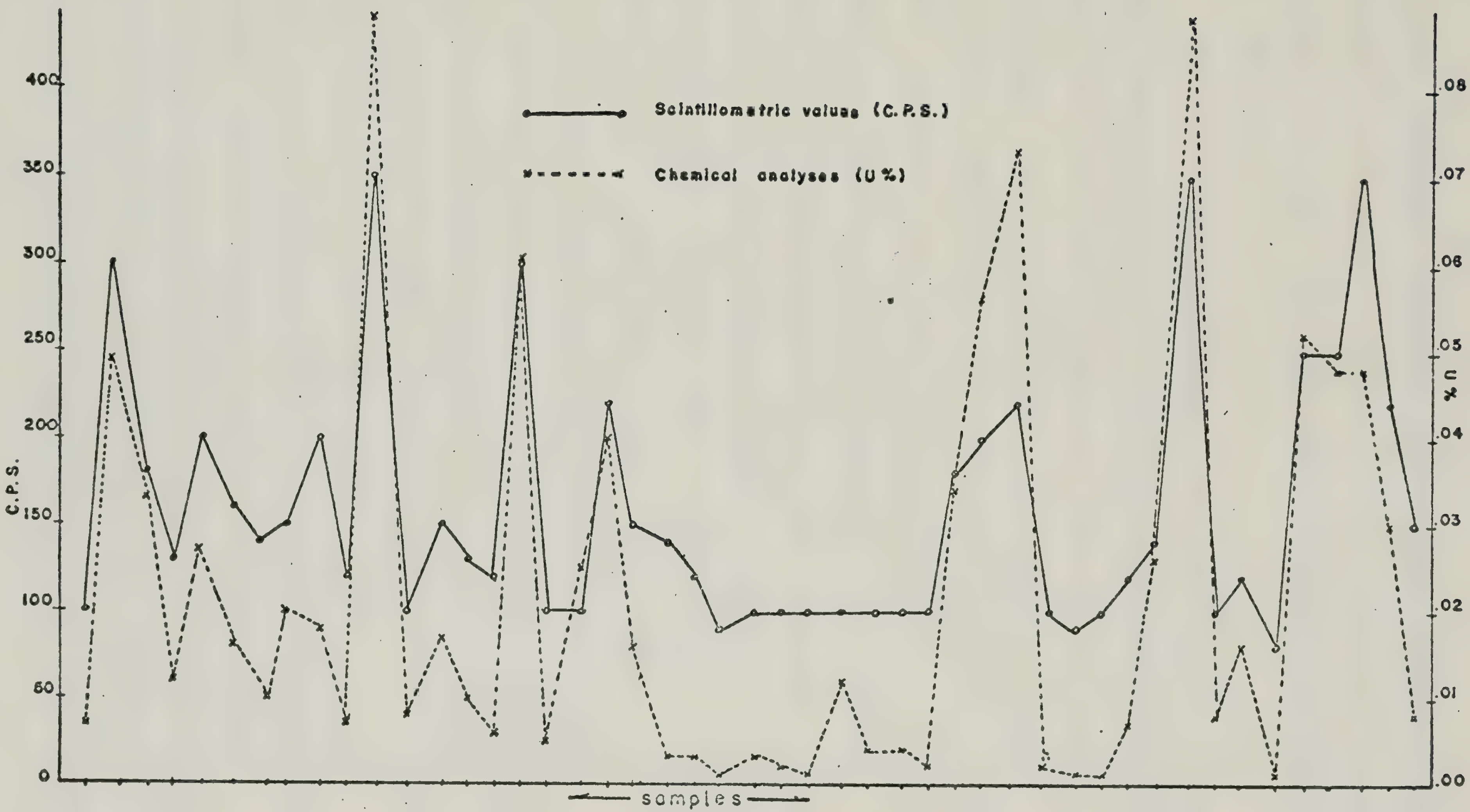


FIG. 10

Correlation between scintillometric values (c.p.s.) and wet chemical analyses (U %)

On a regional scale the radioactive metasediments horizons are relatively narrow, their foliation is consistent in strike, and they are relatively undeformed. (map. No. 1).

The best assay values (up to 0.84% U_3O_8) are from channel samples in the granodioritic granofels containing coarse book-like biotite grains. High values (up to 0.16% U_3O_8) were also found in the migmatite and in the biotite gneiss with incipient migmatization. Marginal low-grade zones (0.01% U_3O_8) adjacent to the main radioactive occurrences are present in the granitic gneiss and are evidenced by a yellow "staining" at the surface. The calc-silicate horizons are barren of uranium mineralization as are the other stratigraphically higher members of the Charlebois Lake Complex.

The work in the area to the end of August 1975 has confirmed the presence of at least 14 widely separated bodies, always related to the same lithologic and stratigraphic units. This situation is most clearly present along the limbs and around the nose of the Pegasus Lake antiform (map No. 1), where radioactivity has been almost invariably noted along the exposed sections of the migmatite and granodioritic granofels. members, extending intermittently over a distance of 20 km. Five different showings have been found in this

particular region. Exposure between individual showings is poor, hence continuity seemed to be also poorly defined. A V.L.F. program was carried out on the swampy and drift-covered areas, between the showings, with no significant results. Stripping and trenching between the showings proved instead that an excellent continuity of mineralization exists. In view of the length of the mineralized zones, appreciable depths of mineralization can also be expected. As Mawdsley pointed out (1952, p. 373), it would be very fortuitous if the present surface is the only horizon at which important radioactive bodies will be found.

Individual description of the showings seems to have only a strictly economic value, since all of the mineralized areas show common petrographic characteristics. For this reason two areas only, the "Row" showing and "Cathy's" showing are considered in some detail in this section. The conclusions made for these two areas have to be retained as valid for most of the other showings.

The "ROW" Showing

This showing is situated along the southern shore of Dramnitzke Bay. The radioactive zone occurs almost continuously along a band about 25 to 35 m from the Bay in a granodioritic granofels-migmatite zone and extends

in length for about 1000 m, later becoming more discontinuous. The sequence of formations here is restricted to the migmatite, granodioritic granofels, and granitic gneiss. Under the migmatite rock type, is included the biotite gneiss with incipient migmatization. No calc-silicates or amphibolite gneisses are present in this showing. Probably they have been eroded and may outcrop under the lake. The complex dips south-southeast, at an angle ranging from 50^{o} to 80^{o}, the last value commonly found close to the shore of the lake. Some faults and joints have been mapped, with a strike direction almost constantly northeast-southwest. Plagioclase-rich granitic gneiss outcrops immediately south of the mineralized zone. The foliation is parallel to the banding of the migmatite. This parallelism is a distinctive feature common everywhere in the Charlebois Lake area. Mineralization preferentially occurs in the granodioritic granofels, where biotite is more abundant and in large books. Molybdenite is concentrated in zones of high radioactivity and its concentration is often clearly proportional to uranium mineralization. Pyrrhotite, magnetite and pyrite are also present in small amounts, usually disseminated in the granodioritic granofels and, to a lesser extent, in the migmatite and granitic gneiss.

Superficial yellow staining, a product of uraninite oxidation, is present especially in the granodioritic granofels and in the granitic gneiss. Upon X-ray diffraction examination, this proved to be uranophane.

Figure 11 shows a tentative correlation between surface geology and relative channel sample assays (U_3O_8%), and the same data obtained from drill core samples.

A good correlation between surface and sub-surface lithology is evident from Figure 11, whilst assay values from the surface are often not in agreement with those obtained from core sample analyses. Section 2040 W (Figure 11) shows an average surface value of .099% U_3O_8 over 15 m, whilst cores from D.D.H. R-12 show .113% U_3O_8 over 16 m, and D.D.H. R-35 shows .119% U_3O_8 over 21 m. The other two sections also prove that there is a substantial increase in U_3O_8% with depth.

The CATHY'S Showing

This showing has been mapped in detail along the 15 trenches (see map No. 1c). The radioactive anomaly is very interesting because of its continuity over 900 m and is also present in the granodioritic granofels and the migmatite.

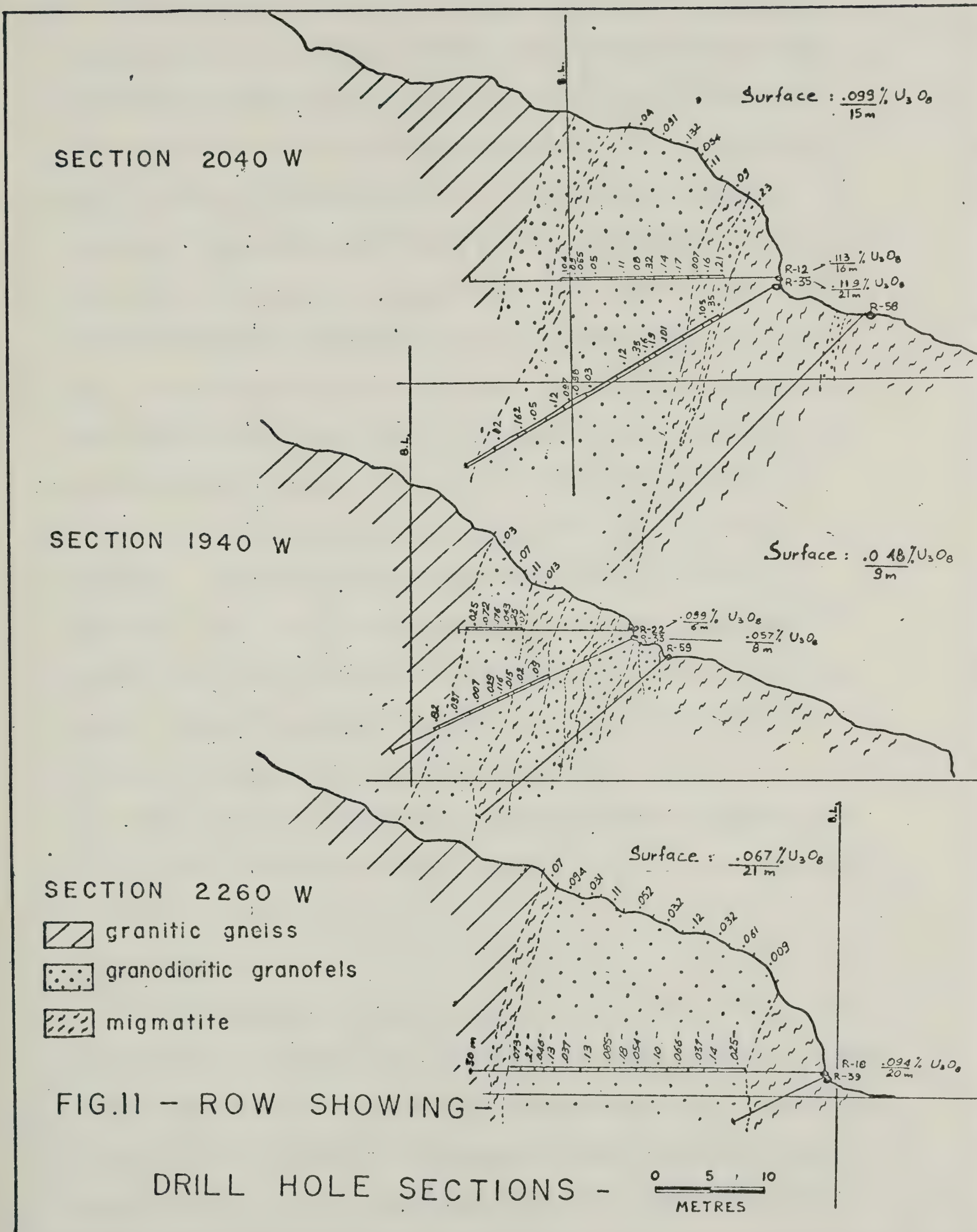


FIG.11 – ROW SHOWING – DRILL HOLE SECTIONS

Yellow and orange staining, products of uraninite oxidation, are commonly visible on the radioactive zone, and the presence of red lichen and red moss is also a good indication of uranium occurrence. Calc-silicates are barren of mineralization. The granitic gneiss presents some minor radioactivity of the order of .004 - .009% of U_3O_8, whilst the best values come from the granodioritic granofels and the migmatite with the U_3O_8 content up to .26%. In this showing we noted that the assay values obtained from samples collected at the surface often correspond to the values obtained from samples collected below the weathered zone (pionjar samples), contrary to what we found in the "Row" showing. This can be explained by the unusual high quartz content present in both pegmatite and migmatite zones. Uraninite has been probably preserved on the surface, 'protected' by the quartz.

The whole sequence strikes northwest-southeast and presents an almost vertical dip (70^{o} - 90^{o} to northeast).

Mineralogy

Mineralogical work discussed here is based upon the examination of about 150 specimens in thin section, X-ray powder diffraction and gamma-ray spectrometry. Uraninite is the primary mineral of economic importance present in this thesis area. Examination of thin sections from

the more mineralized portions of the host rock revealed that the majority of uraninite occurs as isolated, subhedral or euhedral grains within biotite. No distortion of the cleavage planes of the biotite about the uraninite is apparent, although this is the case of inclusions in quartz, sphene, pyrrhotite. High U_3O_8 concentrations (0.]%) were always noted where large book-like aggregations of biotite were present.

The uraninite grains are black and opaque, iron grey in reflected light, and they are often in well developed cubic crystals (Plate X). They present a fairly uniform size, averaging approximately 0.2 mm in diameter. Very commonly, the uraninite crystals are surrounded by a greenish alteration which was identified as a mineral of the gummite group. Sometimes gummite is pseudomorphic after uraninite and is bordered by a narrow rim of very fine, white micaceous aggregate (Mawdsley, 1952, p. 371). The haloes surrounding uraninite crystals are generated by the strong alpha radiation of uraninite. The same type of haloes, but less intense, has also been noted around the zircons (Plate VIId) and, to a lesser extent, around the apatite grains.

J. Barbier (1972) reports that the alpha radiation in the case of zircon and apatite is of the order

of 7 alpha/cm^2/ sec., whilst the alpha radiation flux of uraninite is much more intense (250 alpha/cm^2/sec.). Uraninite grains have also been found, to a lesser extent, in quartz, in feldspars and along the grain boundaries (Plates X and XI).

Superficial "red staining", always associated with very high radioactivity and present especially in the granodioritic granofels and the migmatite, upon microscopic examination proved to be organic matter, i.e. algae with many characteristics of a lichen. Some of this "red staining", when found in fractures, was proved to be not algae or an organic matter, but probably betaphite, a complex calcium, uranium, niobium, tantalium and titanium oxide. (Bill Mercer, 1976, personal communication). One sample, #158, from the "Bell" showing was determined to contain a very small amount of glossy black radioactive mineral, the carbon-bearing uranium mineral thucholite.

Secondary Uranium Minerals

Superficial yellow staining, a product of uraninite oxidation, is present especially in the granodioritic granofels and in the adjacent granitic gneiss, and it is an indicator of medium grade mineralization (0.01 - 0.04% U_3O_8). X-ray diffraction analyses of this staining proved it to be uranophane. ($Ca(UO_2)_2\ Si_2O_7\ 6H_2O$).

Molybdenite is also concentrated in the zones of high radioactivity. Figure 12 and figure 13 show the relationship existing between uraninite and molybdenite (dust-chip percussion samples assayed by Loring Laboratories, Calgary, using wet chemical analyses techniques). Magnetite, pyrite and pyrrhotite are also present in small amounts and are finely disseminated. They do not have any economic significance. Other accessory minerals are apatite, metamict zircon, and sphene.

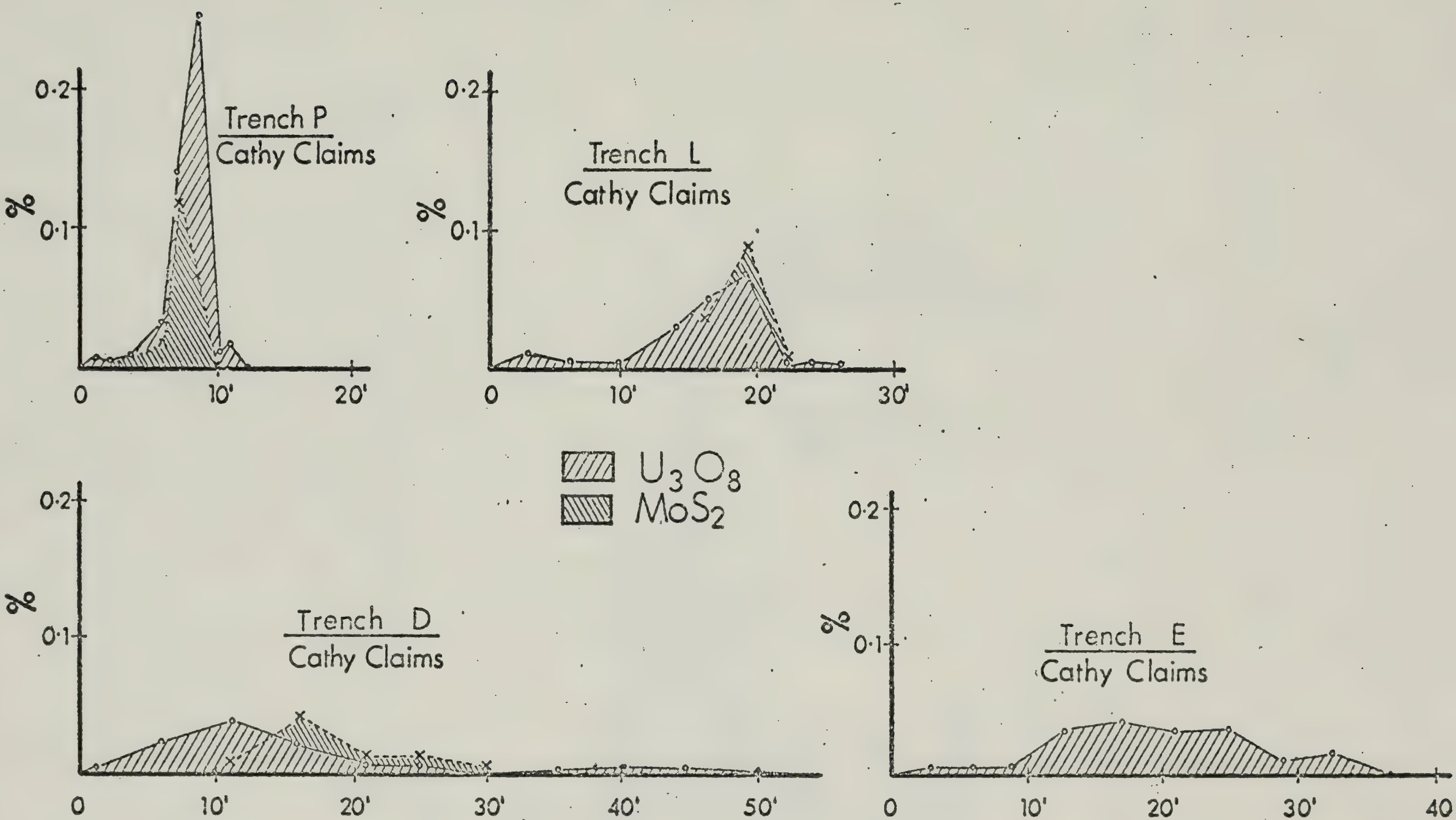


Fig. 12. Relationship between uraninite and molybdenite content (Cathy's showing).

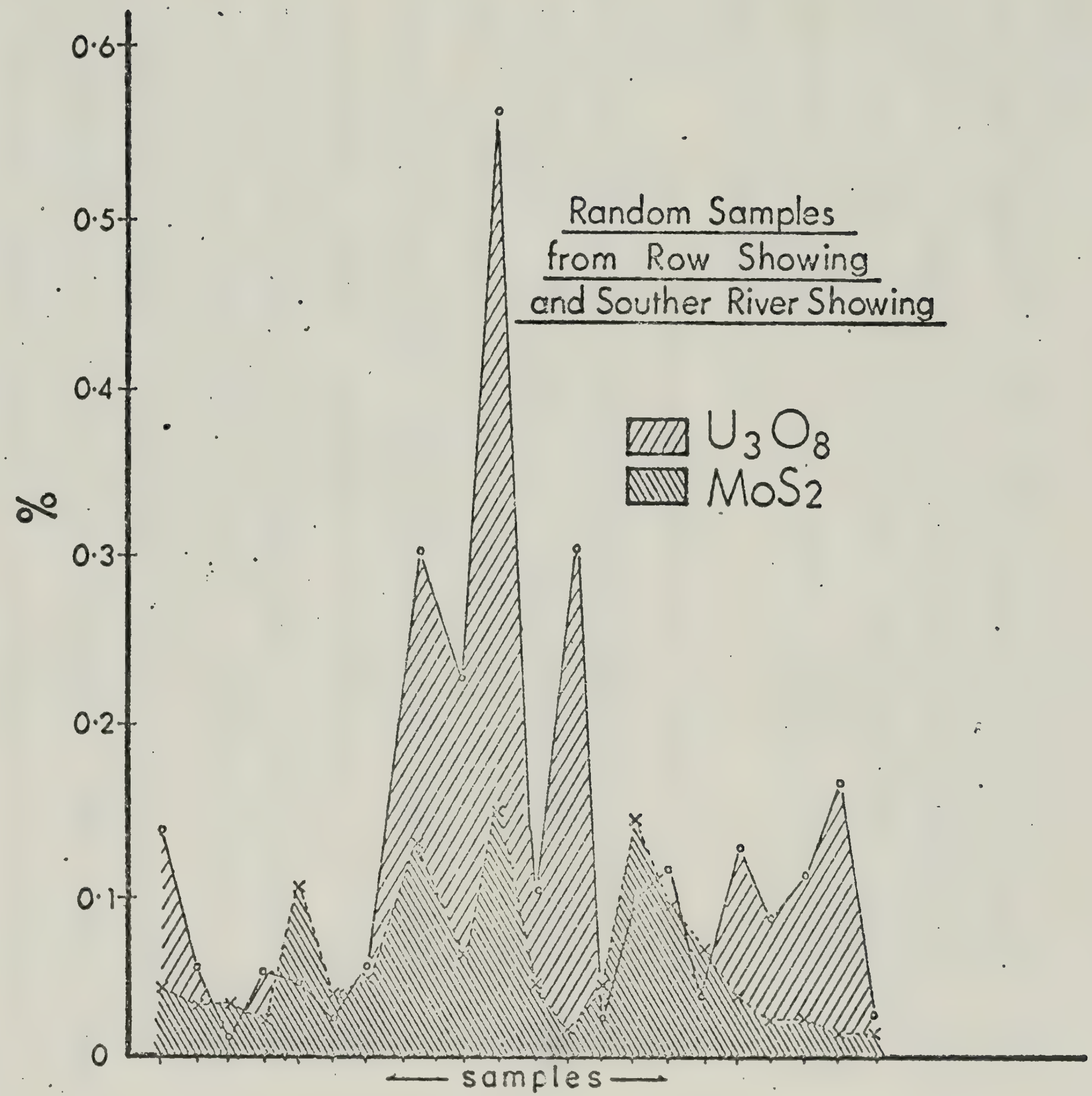


Fig. 13. Relationship between uraninite and molybdenite content. (Row showing and Souter River)

CHAPTER VI

GAMMA-RAY SPECTROMETRIC ANALYSIS

Introduction

An investigation of the distribution of Th, U and K in the metamorphic rocks of the Charlebois Lake Complex has been done with the aim of investigating the suggestion that a metasedimentary member of the Complex might be the source of the uranium mineralization.

A set of 155 samples was collected which represented several cross-sections cutting across the mineralized area and comprising all the members of the Charlebois Lake Complex. The sample locations are shown on map No. 1.

Of the 155 specimens collected, only 70 were used for quantitative gamma-spectrometric analyses: 9 of granitic and tonalitic gneisses, 27 of granodioritic granofels, 9 of migmatites and biotite gneisses with incipient migmatization, 11 of hornblende gneisses and amphibolites, 5 of calc-silicate lithologies and 9 of biotite gneisses. Each sample was a hand specimen weighing about 2 kg, free of all weathered material. All of them are surface or near-surface samples and since the area has been glaciated about 10,000 years ago, weathering is restricted to a thin surface film, and its effects on the uranium content and isotopic equilibria were assumed to be negligible.

All spectrometric work was done in the Geology Department, University of Alberta, Edmonton.

Procedure

Samples were crushed to obtain 500 grams of fine powder and were mixed to ensure complete homogenization. Two hundred grams of the original material were selected as "standard weight" and sealed in 400 ml plastic containers, 11.5 cm in diameter and 4.5 cm high, which were after 3 weeks placed at a distance of 2.5 cm from the detecting crystal.

Equipment used:

1) 1024 channel pulse height analyser (Ortec 6220).
2) Bicron detector: 5" x 6" (NaI(Tl) crystal, 152 B01 photomultiplier tube with resolution 8.2% for 661 KeV peak of 137 Cs at 1000 V.
3) Spectroscopy amplifier: (Ortec 452).
4) High voltage power supply: (Ortec 456).
5) Readout: Ortec 222 Teletype.
6) Shielding: 12.5 cm thick lead.

Operating conditions:

1) H.V. Power: 900 v.
2) Amplifier: coarse gain: 10, fine gain: 1.0. S.T.: 1.0 u sec. B.P.: neg. output: -10 v, BLR: out. Delay: out.
3) A.D.C.: Address 1024. Digital offset: off.

P.H. Analysis region: Lower level: 3.18-Upper level: 7.69.

4) Memory: full, Storage: add.

5) Preset: time.

6) Functional mode: PHA

The calibration procedure has been done with standard techniques using the following standards of the Atomic Energy Commission, New Brunswick Lab., and of the Geology Department, University of Alberta.

Standard No.	Th%	U%	K%	Wt.(g)	Description
NaCl	.00	.00	.00	200.0	
KCl	.00	.004	52.447	200.0	
NBL #73	n.d.	1.0	.01	193.08	Uranium ore
NBL #74	n.d.	.1	.01	187.44	Uranium ore
NBL #75-A	n.d.	.05	.01	190.93	Uranium ore
NBL #76-A	n.d.	.01	.01	203.18	Uranium ore
NBL #79-A	1.00	.04	.01	188.19	Thorium ore
NBL #80	.10	.004	n.d.	193.5	Thorium ore
NBL #81-A	.05	.002	n.d.	193.1	Thorium ore
NBL #83-A	.01	.0004	.01	202.5	Thorium ore
#42-2	n.d.	2.0	.01	196.69	Counter calibration sample
RDM U-5	.00106	.00028	1.9	253.09	Carbonate-rich intrusive breccia, Simpson Is. N.W.T.
RDM U-7	.00116	.00101	2.2	250.0	Siltstone, Simpson Is. N.W.T.
FM 26	n.d.	n.d.	6.306	200.0	Granitic gneiss
FM 151	n.d.	n.d.	6.969	200.0	Granitic gneiss
FM 218	n.d.	n.d.	6.14	200.0	Pegmatite
4015-B	.0009	.000097	1.382	200.0	Biot.-hornbl.-plag. gneiss
4016-A	n.d.	n.d.	1.382	200.0	Garnet mineral-plagioclase gneiss

(n.d.: no determination made)

The three energy peaks for the Th (^{232}Th series), U (^{238}U series), and K determinations were the 2.615 MeV (Tl 208), 1.764 MeV (Bi 214) and 1.461 MeV (K 40) peaks respectively, and it was assumed that a secular radioactive equilibrium existed in ^{232}Th and ^{238}U series. The analyser was set with the ^{40}K channel 393, ^{214}Bi in channel 492, and ^{208}Tl in channel 679. Peak summation: K: 31 channels (i.e. 378-408), U: 29 channels (i.e. 478-506), Th: 31 channels (i.e. 664-694). The total number of counts under each peak was automatically integrated and then divided by the counting time to give the count rate (in cps). This was also done for the background and the net count rate under each peak was determined by subtracing the background count rate.

The analytical formulae which were used to calculate concentrations from the Th, U and K channel count rates are given below:

$$eTh(\%) = K_1[C(Th)]$$

$$eU(\%) = K_2[C(U) - \alpha C(Th)]$$

$$K(\%) = K_3[C(K) - \gamma[C(U) - \alpha C(Th)] - \beta C(Th)]$$

where:

eTh(%),eU(%): equivalent concentration of thorium and uranium assuming series equilibrium conditions exist in the assayed sample.

K(%): concentration of potassium in assayed sample.

C(Th),C(U),C(K): count rates produced in the Th, U and K channels under "assaying conditions" minus the background count rate for each channel.

α γ β : constants can be determined for a particular source configuration using procedures described in Scintrex operating manuals.

The counting time for each analysis was kept constant at 40,000 seconds, in order to obtain good assay precision, within $\pm$ 4% for U, $\pm$ 2% for Th, $\pm$ 1% for K.

Presentation of Data and Discussion of Results

All data from this analytical study have been tabulated by rock-type. Arithmetic means for the various elements for each rock-type have been calculated and are shown in Tables XIII-XVIII. Some of the tabulated values were regarded as unrealistic, as suggested by the histograms (Fig. 16 and 17). The standard deviations also show that the rejection of these values is justified.

The unrealistic values are placed in parentheses in the tables and they were omitted in the calculation of the new arithmetic means. These corrected arithmetic means are shown in Tables XIII-XVIII. The corrected means are often significantly different from the uncorrected ones and are used instead of the uncorrected ones in all comparisons made in this text.

It has to be pointed out that all the samples analyzed for Th, U and K were collected within the radioactive zones or along the contacts of the same. The results obtained, therefore, do not have a regional validity, but they are representative of the mineralized area only.

Histograms showing the distribution of values for the radioelements and their ratios are given in Fig. 16 and 17. The large scatter in results, especially evident for the calc-silicate rocks and the hornblende gneiss and amphibolite is in part due to the small number of specimens analyzed, and in part to the effect of inhomogeneities inherent to the rock-type.

For comparative purposes Table XIX gives the average concentration of U, Th and K for the continental crust and granitic rocks as reported by various authors. The average U, Th and K concentrations for each rock-type of the Charlebois Lake Complex have been compared to the average content of these elements in analogous rock-types (Fig. 14).

From Fig. 14(a) it appears that the average uranium content detected in the rocks of the Charlebois Lake (curve X) area is at least twice as great as the average content of the same element in corresponding average crustal rock-types, in other non-mineralized areas (curve X'). The anomalously high U values are not restricted to the granodioritic granofels and migmatitic rocks, but they are also found in the rocks adjacent to the highly mineralized zone.

TABLE XIII

Rock Type: Granodioritic Granofels

Number of Specimens Analyzed: 27

Specimen No.	Th (ppm)	U (ppm)	K (%)	Th/U	Th/K ($x10^4$)	U/K ($x10^4$)
39	2.45	23.32	(6.30)	0.10	0.39	3.70
41	224.0	1026.12	2.73	0.21	82.05	375.87
42	116.24	197.86	1.5	0.58	77.49	131.91
77	130.0	644.0	2.43	0.20	53.50	265.02
88	35.0	147.0	2.15	0.23	16.28	68.37
150	58.61	297.07	3.05	0.19	19.22	97.40
151	111.86	625.4	(6.96)	0.02	16.07	89.86
154	93.00	403.00	(0.59)	0.23	157.63	683.05
155	233.05	1297.65	3.80	0.18	61.33	341.49
156	260.00	1414.00	(6.88)	0.18	37.79	205.59
162	125.78	266.44	3.88	0.56	32.42	58.36
163	312.00	202.77	2.46	(1.54)	126.83	82.43
164	37.96	32.93	4.42	(1.15)	8.59	7.45
165	57.96	142.57	2.56	0.41	22.64	55.69
202	36.00	223.00	3.64	0.16	9.89	61.26
202-A	33.00	169.00	3.76	0.20	8.78	44.95
203	155.64	856.00	2.15	0.18	72.39	398.14
204	191.66	1259.32	2.18	0.15	87.92	577.67
205	114.72	664.92	(0.5)	0.17	229.44	(1329.84)
211	156.00	986.49	(5.28)	0.16	29.55	186.84
215	113.00	573.15	(0.8)	0.20	141.25	716.44
217	243.51	627.23	1.95	0.39	124.88	321.66
221	87.50	696.70	2.22	0.13	39.41	313.83
229	129.94	714.93	3.90	0.18	33.32	183.32
231	(1945.00)	(5945.00)	2.64	0.33	(736.74)	(2251.89)
233	1343.90	5427.35	3.11	0.25	(432.12)	(1745.13)
Arithmetic mean	257.00	1019.15	3.20	0.32	103.34	402.92
Median	129.94	625.40	2.73	0.20	53.50	205.52
Standard deviation .	425.13	1461.16	1.72	0.33	155.39	540.25

Remarks: The values in parentheses were not used to calculate the new arithmetic mean below.

New arithmetic mean	146.04	560.45	2.95	0.24	63.77	231.33

TABLE XIV

Rock Type: Migmatite

Number of Specimens Analyzed: 9

Specimen No.	Th (ppm)	U (ppm)	K %	Th/U	Th/K $(x10^4)$	U/K $(x10^4)$
40	136.00	223.18	2.8	0.61	48.57	79.71
46	143.00	162.00	3.1	(0.88)	46.13	52.26
55	280.70	624.30	3.25	0.45	86.37	192.09
59	98.60	426.60	3.17	0.23	31.10	134.57
67	544.00	(2624.00)	3.18	0.21	171.61	(825.16)
86	75.00	334.69	4.3	0.22	17.44	77.83
89	121.57	106.34	4.5	(1.14)	27.02	23.63
206	(966.00)	(4511.81)	3.24	0.21	(298.15)	(1392.53)
216	103.00	156.00	3.10	0.66	33.23	50.32
Arithmetic mean	274.21	1018.77	3.40	0.51	84.40	314.23
Median	136.00	334.69	3.18	0.45	46.13	79.71
Standard Deviation..	298.09	1528.74	0.58	0.34	93.06	474.95

Remarks: The values in parentheses were not used to calculate the new arithmetic mean below.

New Arithmetic mean.	187.66	290.44	3.40	0.37	57.68	87.20

TABLE XV

Rock Type: Granitic and Tonalitic Gneiss

Number of Specimens Analyzed: 9

Specimen No.	Th (ppm)	U (ppm)	K %	Th/U	Th/K $(x10^4$	U/K $(x10^4)$
7	15.20	16.80	3.62	0.90	4.20	4.64
26	24.35	(8.43)	(6.30)	2.89	3.87	(1.34)
57	(57.87)	11.77	3.64	(4.92)	15.90	3.23
58	27.30	15.18	3.45	1.80	7.91	4.40
87	13.19	19.31	(6.86)	0.68	1.92	2.81
153	15.20	21.60	3.48	0.70	4.37	6.21
157	19.39	(49.55)	3.63	0.39	5.34	(13.65)
168	(68.14)	23.32	2.56	2.92	(26.26)	9.11
169	12.50	20.60	2.82	0.61	4.43	7.30
Arithmetic mean	28.13	20.73	4.04	1.76	8.24	5.85
Median	19.39	19.31	3.62	0.90	4.43	4.64
Standard Deviation..	20.55	11.82	1.50	1.53	7.88	3.77

Remarks: The values in parentheses were not used to calculate the new arithmetic mean below.

New Arithmetic mean.	18.16	18.37	3.31	1.37	5.99	5.39

TABLE XVI

Rock Type: Biotite Gneiss

Number of Specimens Analyzed: 9

Specimen No.	Th (ppm)	U (ppm)	K (%)	Th/U	Th/K ($x10^4$)	U/K ($x10^4$)
18	17.12	10.31	2.80	1.66	6.11	3.68
19	(0.46)	(4.24)	1.00	(0.11)	(0.46)	4.24
23	(65.27)	18.10	2.92	(3.61)	(22.35)	6.20
38	37.90	(22.30)	3.06	1.70	12.39	7.29
65	29.62	11.81	2.89	2.51	10.25	4.09
79	15.23	11.38	2.22	1.34	6.86	5.13
80	17.87	(23.38)	3.2	0.76	5.58	7.31
208	14.81	(22.36)	(6.9)	0.66	2.15	(3.24)
228	15.88	7.38	(0.8)	2.15	19.85	(9.23)
Arithmetic mean	23.79	14.58	2.86	1.63	9.56	5.60
Median	17.12	11.81	2.92	1.66	6.86	5.13
Standard deviation ..	18.69	7.11	1.75	1.06	7.51	2.03

Remarks: The values in parentheses were not used to calculate the new arithmetic mean below.

New arithmetic mean	19.03	11.80	2.58	1.54	8.72	5.42

TABLE XVII

Rock Type: Hornblende Gneiss and Amphibolite

Number of Specimens Analyzed: 11

Specimen No.	Th (ppm)	U (ppm)	K (%)	Th/U	Th/K ($x10^4$)	U/K ($x10^4$)
21	14.23	3.15	1.14	4.52	12.48	2.76
27	1.95	(0.05)	(1.00)	(39.00)	1.95	(0.05)
28	12.97	3.12	0.73	4.16	17.77	4.27
30	(0.46)	5.65	0.81	0.08	0.57	6.98
33	(19.90)	(14.20)	(0.57)	1.40	(34.91)	(24.91)
37	5.86	5.06	(0.70)	1.16	8.37	7.23
96	(0.41)	(11.80)	(0.58)	0.03	0.71	(20.34)
207	(17.12)	8.65	1.05	1.98	16.30	8.24
213	9.39	8.21	0.83	1.14	11.31	9.89
227	6.14	3.02	1.03	2.03	5.96	2.93
240	2.74	4.9	1.14	0.56	2.40	4.30
Arithmetic mean	8.28	6.16	0.87	5.10	10.25	8.35
Median	6.14	5.06	1.05	1.40	8.37	6.98
Standard deviation ..	6.90	4.19	0.21	11.34	10.22	7.66

Remarks: The values in parentheses were not used to calculate the new arithmetic mean below.

New arithmetic mean	7.61	5.22	0.96	1.71	7.78	5.83

TABLE XVIII

Rock Type: Calc-silicate Rocks

Number of Specimens Analyzed: 5

Specimen No.	Th (ppm)	U (ppm)	K %	Th/U	Th/K ($x10^4$)	U/K ($x10^4$)
22	6.48	6.10	1.2	1.06	5.40	(5.08)
34	(0.92)	4.55	(0.4)	0.20	2.30	11.38
85	1.96	(15.86)	1.36	(0.12)	(1.44)	11.66
212	(8.8)	9.58	1.1	0.92	(8.0	8.71
214	6.94	7.12	1.3	0.97	5.34	5.48
Arithmetic mean	5.02	8.64	1.07	0.65	4.50	8.47
Median	6.48	7.12	1.2	0.2	5.34	8.71
Standard deviation .	3.40	4.43	0.39	0.45	2.64	3.13

Remarks: The values in parentheses were not used to calculate the new arithmetic mean below.

New arithmetic mean	5.13	6.84	1.24	0.79	4.35	9.31

TABLE XIX

Distribution of the Elements in the Earth's Crust Expressed in p.p.m.

(After Turekian and Wedepohl, 1961)

	Igneous Rocks			Sedimentary Rocks		
	Basaltic	Granitic		Shales	Sandstone	Carbonate
		High Ca	Low Ca			
U	1	3	3	3.7	0.45	2.2
Th	4	8.5	17	12	1.70	1.7
Th/U	4	2.8	5.6	3.2	3.78	0.7

Uranium and Thorium Content of Canadian Shield Areas

(Burwash and Cumming, 1976)

	U p.p.m.	Th p.p.m.	Th/U
Western Canada Basement	4.13	21.1	5.11
Canadian Shield (Shaw 1967)	2.45	10.3	4.20
Bear Province	8.1	35.7	4.41
Slave Province	1.7	8.4	4.94
Churchill Province	2.6	15.5	5.96
Superior Province (Eade & Fahrig, 1971)	1.2	9.7	8.08

Average Th, U and K Contents of Granitic Rocks

(Killeen and Heier, 1974)

	Th ppm	U ppm	K %	Th/U
Canadian Shield (Shaw 1967)	10.3	2.45	2.58	4.20
Granitic Rocks (Heier & Rogers, 1963)	17.36	4.75	3.79	3.65
Granodioritic (Clark et al, 1966)	9.3	2.6	2.55	3.58

Granitic Rocks	$Th/K \times 10^4$	Ratio:	4.9	(Heier & Rogers, 1963)
	$U/K \times 10^4$	Ratio:	1.2	
Canadian Shield	$U/K \times 10^4$	Ratio:	0.95	(Shaw, 1967)

The granitic and tonalitic gneisses of the area show an average of 18.37 p.p.m. U, which is six times as great as the average previously found in the granitic gneisses of the Churchill Province (Burwash and Cumming, 1976, p. 286).

The hornblende gneisses and amphibolites have a U content 5 times as great as the world average for similar rock-types.

Similarly, the calc-silicate rocks and the biotite gneiss have U contents 3 times as great as the average for analogous rocks elsewhere.

Figure 14(b) shows that the average Th concentration for the rocks of the Charlebois Lake area (curve Y), represents from 1 to 15 times the average content of the same element in analogous rock-types (curve Y'). It is important to note that the average Th concentration in the granitic and tonalitic gneisses of this area (18 p.p.m.) is approximately the same as that reported by Burwash and Cumming (1976, p. 286) for the gneisses of the Churchill Province (15 p.p.m.).

Thorium concentrations in the calc-silicate rocks, in the hornblende gneiss and in the biotite gneiss of the Charlebois Lake Complex are approximately one and a half times as great as the world average content of the same element in analogous rock-types. Highly anomalous Th values are found in the granodioritic granofels and in the migmatite (150 p.p.m., versus 15-18 p.p.m., as reported for analogous rock-types).

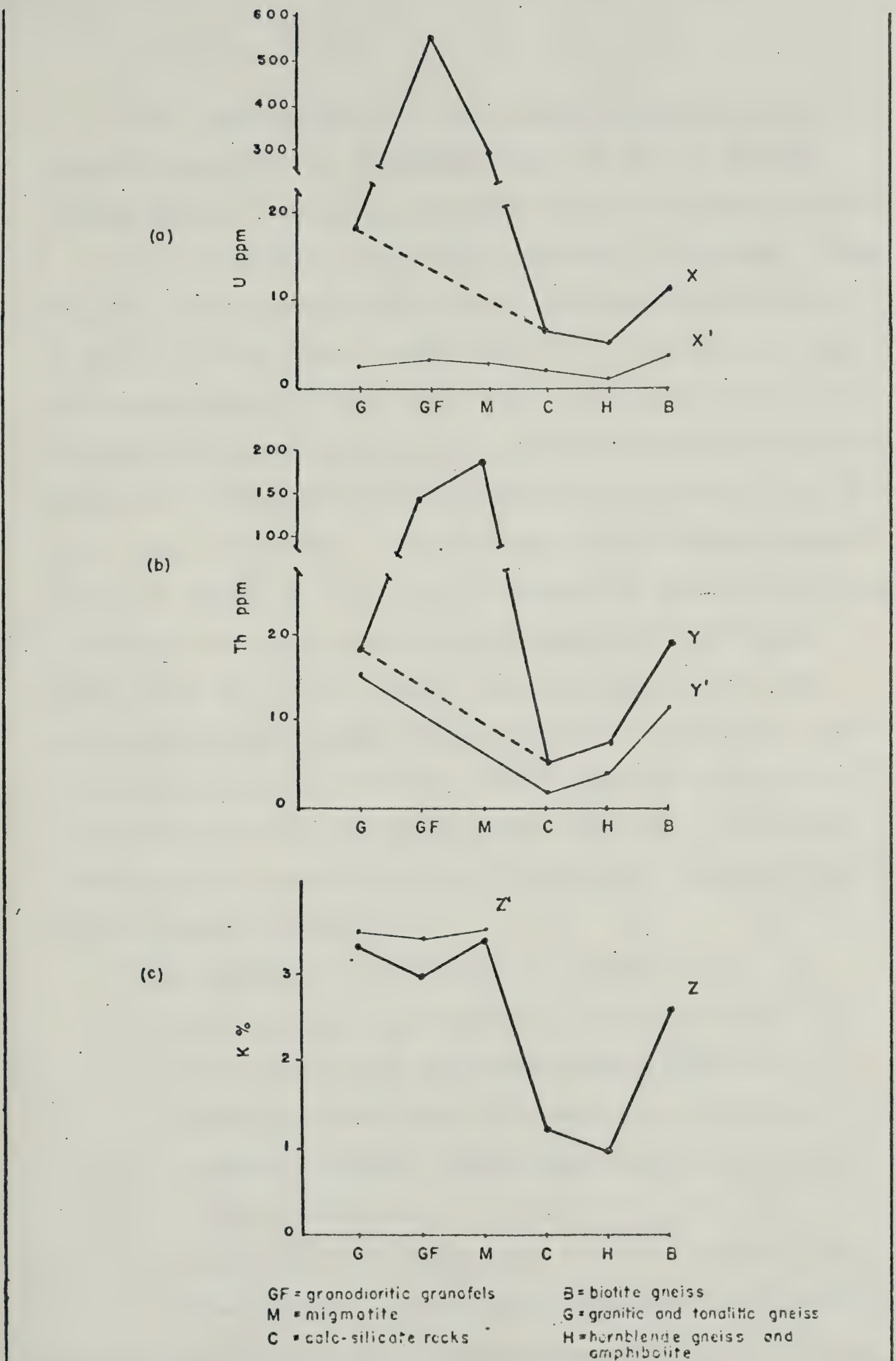


Figure 14 Relation of the contents of each of the elements analyzed in a given rock-type of the Charlebois Lake area (curves x, y, z) to the average content of these elements in analogous rock-types elsewhere (curvex x', y', z').

The K content (Fig. 14 (c)) of the Charlebois Lake Complex (curve Z) is noticeably similar to the average values for corresponding average world rock-types (curve Z').

It is possible to gain one important conclusion from Fig. 14, if we separately compare the trend of the curves X and X' in Fig. 14(a), and Y and Y' in Fig. 14(b). The difference between the trend of the curves is small, if we exclude the highly mineralized granodioritic granofels and migmatitic rocks from the comparison (see broken lines in Fig. 14(a) and 14(b)). A good parallelism exists between curves Y and Y' in Fig. 14(b), suggesting that very little liberation or concentration of Th minerals took place within the area. Fig. 14(a) does not present the same good parallelism between curves X and X', as in Fig. 14(b). The uranium concentration in the Charlebois Lake granitic and tonalitic gneisses is at least 10 p.p.m. higher than what would be required in order to obtain a certain parallelism between the curves.

This suggests two different hypotheses:

1) The granitic and tonalitic gneisses of the Charlebois Lake area have been enriched in U, possibly during the Hudsonian orogeny and consequent tectonic, metamorphic and coeval metasomatic effects.

2) The rocks were originally U rich. In this case the granitic and tonalitic gneisses are likely to be considered as the source-rock for the uranium

deposits present in the adjacent granodioritic granofels and migmatites.

To conclude, the profiles in Fig. 14 indicate that:

(a) All the rocks in the Charlebois Lake area are abnormally U-rich, with the highest concentration occurring in the granodioritic granofels and in the migmatite.

(b) The granodioritic granofels and migmatites are also abnormally Th-rich, whilst the granitic and tonalitic gneisses contain normal Th concentrations. The other units of the complex show Th concentrations approximately twice as great as normal values.

In order to better understand the relationship of uranium to the other radioelements, Th and K were plotted against the U content of each rock-type of the Charlebois Lake Complex. A series of curves should theoretically be obtained from the graphs on Fig. 15. These curves describe the relationship of U to the other elements in a given rock-type and in some cases they may give valid indications of a possible uranium source-rock. In this particular case the relationship between Th and K against U is not very clear, for most of the rock-types. A larger number of analyzed specimens is probably required in order to obtain better results.

Excellent positive Th/U relationship exists instead in the granodioritic granofels and migmatites (Fig. 15).

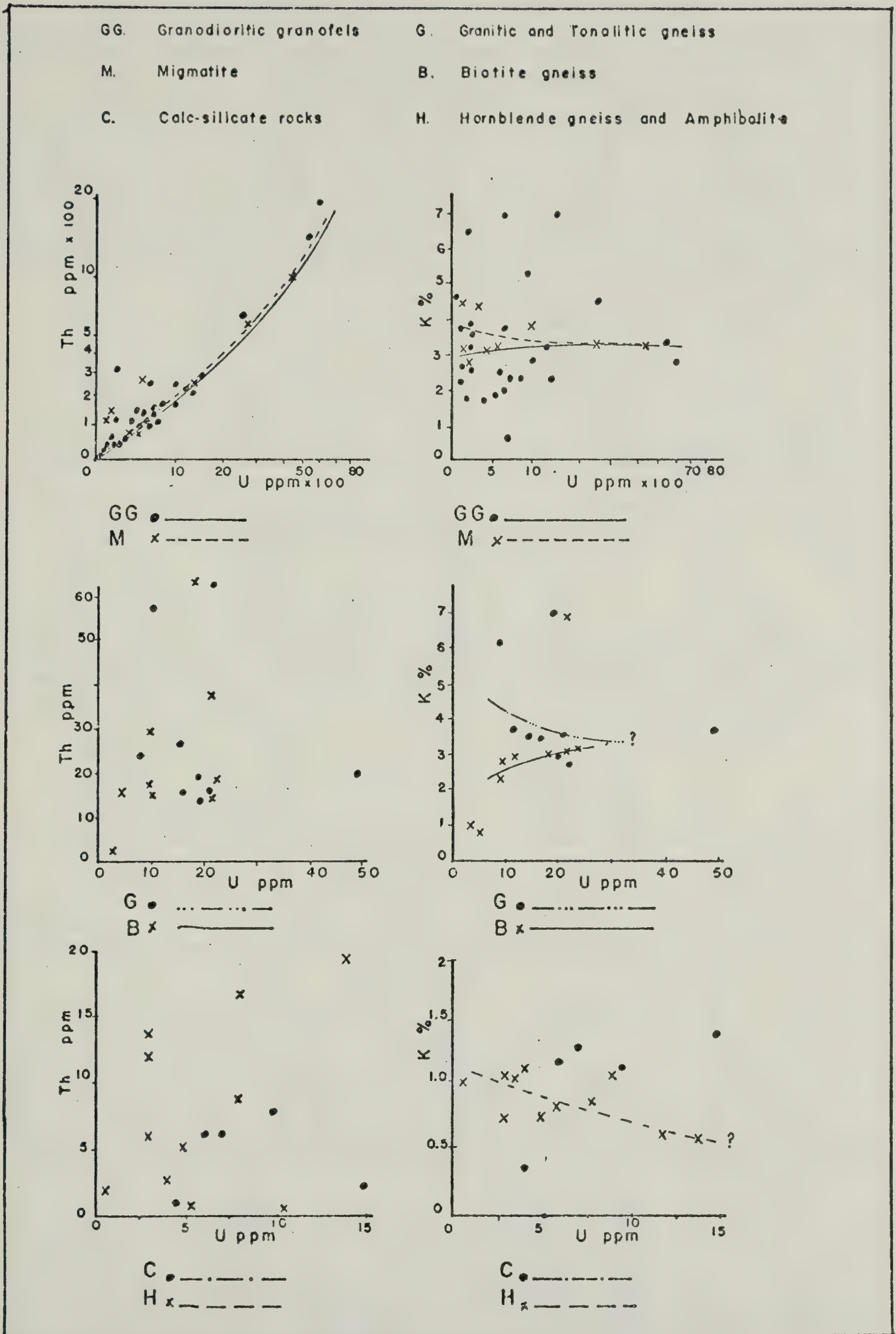


FIG. 15 Relation of uranium to thorium and potassium in the rocks of the Charlebois lake area.

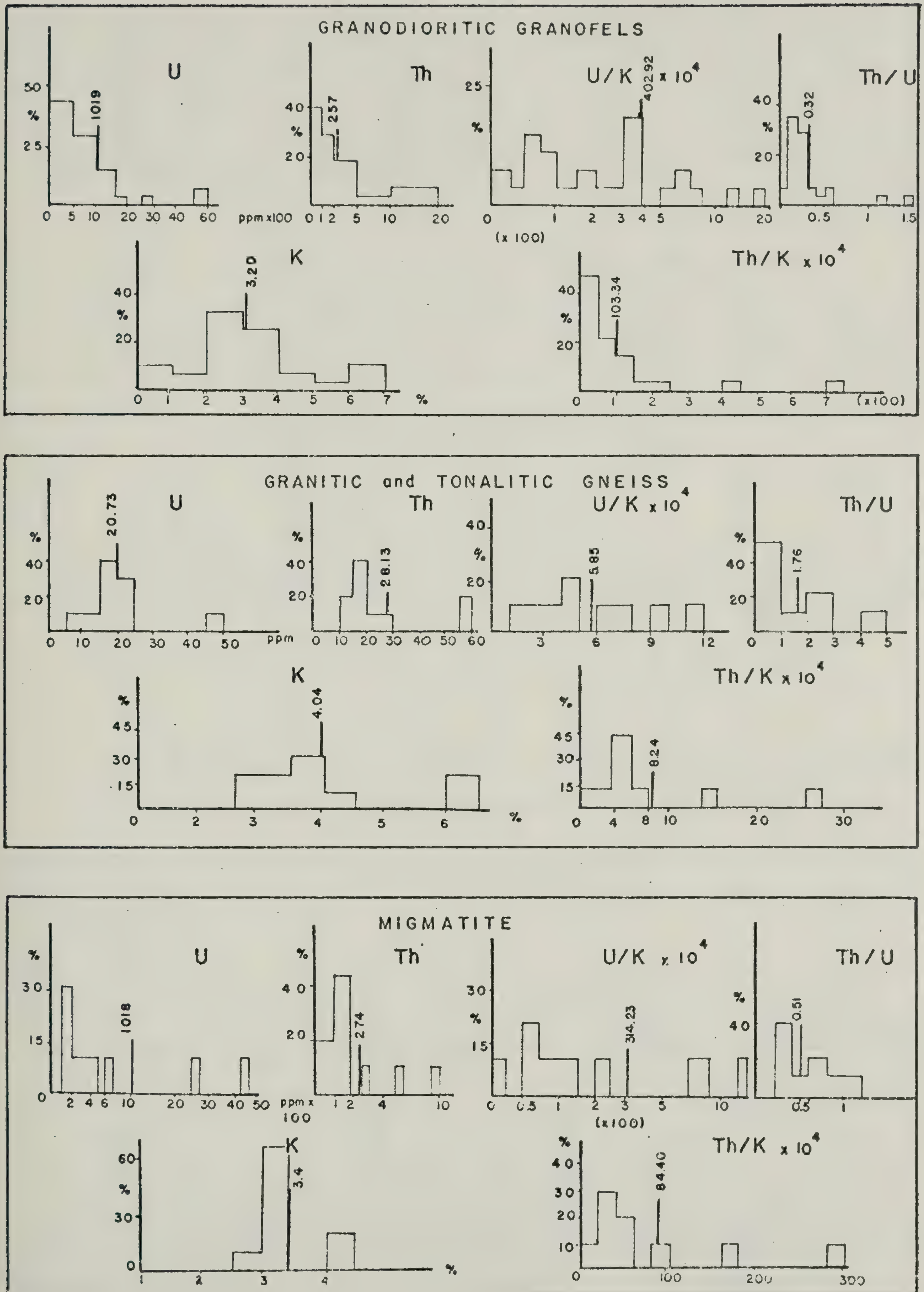


Fig. 16. Histograms of the three radioelements and their ratios in the granodioritic granofels, granitic and tonalitic gneiss, and migmatite rocks.

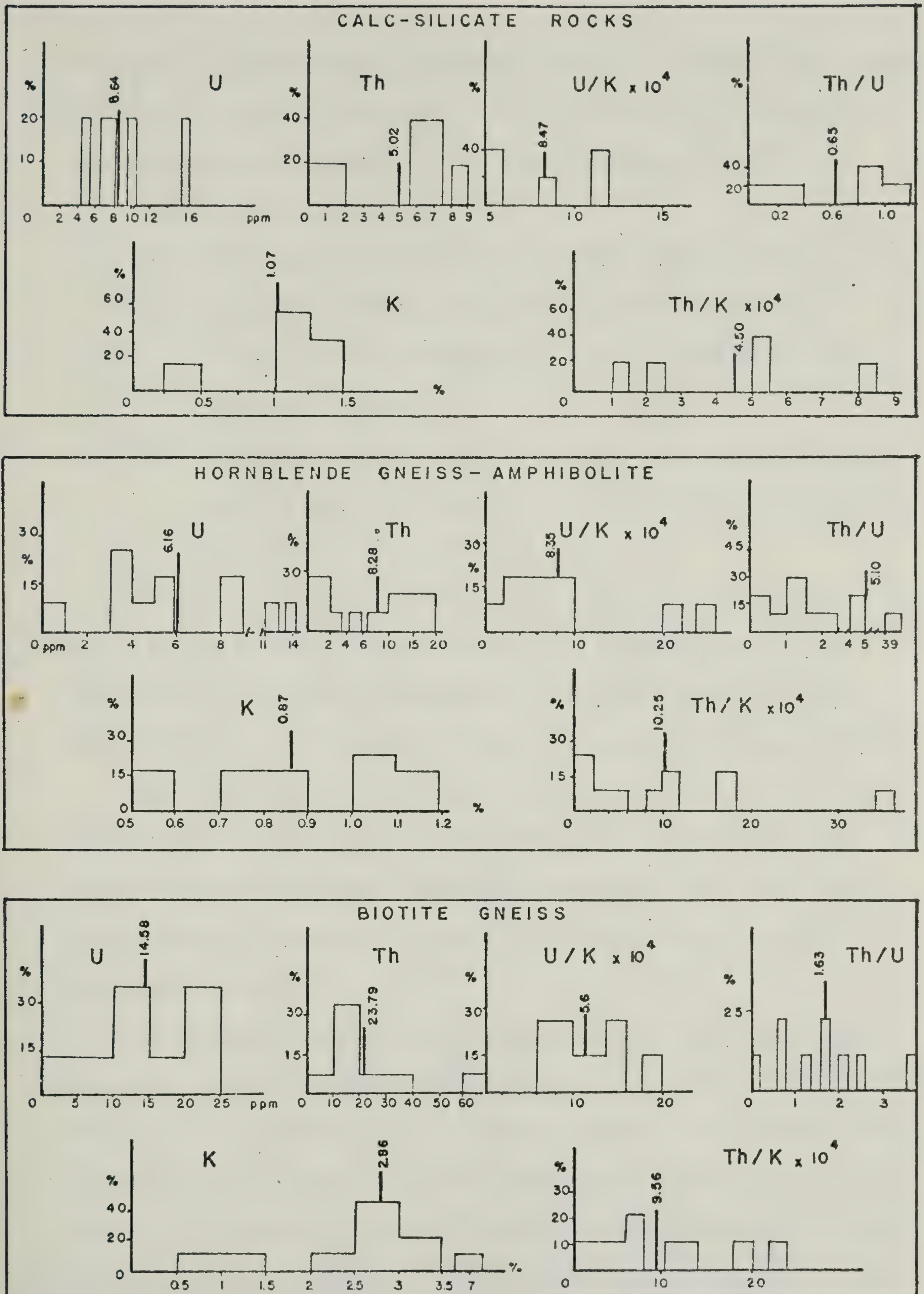


Fig. 17. Histograms of the three radioelements and their ratios in the calc-silicate rocks, hornblende gneiss and amphibolite, and biotite gneiss.

In these two rock types uranium content is almost constantly 4 times as great as thorium. (In granodioritic rocks Th concentration is normally 3.7 times greater than U).

This may suggest that:

(a) both uranium and thorium were deposited with the original sediments in the constant ratio of 4 to 1 and no successive events modified this original ratio.

(b) uranium and thorium have been introduced later, in the constant ratio of 4 to 1, as a result of a process of solid solution .

Natural uraninite may in fact contain large amounts of Th in solid solutions, especially in pegmatites, whilst Th is often virtually lacking in the uraninite of hydrothermal veins and sandstone-type deposits (Frondel, 1958).

The first hypothesis (a) is rather unlikely, considering that the original uranium-bearing sedimentary sequence experienced the Hudsonian orogeny, and that during that orogeny a constant U/Th ratio would very probably have been modified.

No relationship exists between K and U in the granodioritic granofels and in the migmatite, although it seems that U is independent of K. This appears to indicate that the migration of potash, that took place within the rock itself for relatively short distances (see chapter on metamorphism), as a result of metamorphic differentiation, is not related to any possible U mobilization (enrichment or

depletion) that might have taken place or, at least, uranium did not follow that pattern of potassium. This situation is rather uncommon, if compared with similar anomalous U and Th rich Precambrian granitic Provinces, e.g. those of the Telemark area, Norway, described by Killeen and Heier (1975). The radiometric results presented by these authors show that Th, U and K contents generally increase through the processes of metasomatism (Killeen and Heier, 1975, p. 75).

On the other hand, an increasing K induced by metasomatism could effect a decrease in uranium, as shown by Killeen and Heier, (1975) for the Flå granite, in southern Norway. This second alternative is quite justifiable, as if sufficient heating occurred to cause K-metasomatism then it could have easily resulted in concomitant U migration.

A doubtful negative Th/U relationship exists in the granitic and tonalitic gneisses of the area (increasing in uranium - decreasing in thorium), although the curve is difficult to define, due to the limited number of specimens analyzed. The mean value of Th/U for the granitic and tonalitic rocks of the Charlebois Lake area is 1.76, which is about half of the average value for the granitic material in the Canadian Shield. It would be of interest to study Th and U distribution in the granitic and tonalitic gneisses in more detail, e.g. analyzing a set of samples collected at regular intervals across the Pegasus Lake overturned anticline: this could possibly give some indications con-

cerning the behaviour of Th and U as we approach the highly mineralized area.

All the other rocks of the Charlebois Lake Complex show a doubtful positive Th/U relationship, and no U/K relationship.

Conclusions

(1) All the rocks of the Charlebois Lake Complex are enriched in uranium by at least a factor of 3, with the highest concentration being in the granodioritic granofels and in the migmatite. U concentration in these rock-types is indicated by the difference between the uncorrected arithmetic means and the corrected ones in Tables XIII and XIV, by the histograms of the radioelements, and by their ratios (Fig. 16 and 17).

(2) All the rocks of the Charlebois Lake Complex are high in Th by at least a factor of 1.5, with the exception of the granitic and tonalitic gneisses which have Th contents slightly higher than the average contents of the same element in analogous rock-types. Highly anomalous values are found in the granodioritic granofels and in the migmatite. Again the histograms of Fig. 16 and 17 and the tabulated arithmetic means (Tablex XIII and XIV) suggest that some Th concentration took place in these rock-types.

(3) An excellent positive Th/U relationship exists in the granodioritic granofels and in the migmatite (Fig. 15), with uranium almost constantly 4 times as high as Th. It

is probable that uranium and thorium have been introduced in the rocks in this constant ratio as solid solutions.

(4) Mobilization of uranium in the area is not related to processes of potash migration.

(5) The granitic and tonalitic gneisses are most likely to be the source-rock for the uranium deposit since:

(i) their uranium content is high , relative to the granitic averages of the Churchill Province, of a factor of six. (ii) they are always immediately adjacent to the highly mineralized units. (iii) they present enough volume to have produced such a spatially and continuous uranium mineralized zone. Uranium was possibly deposited as clastic grains together with thorium, when the original premetamorphic granitic equivalent sediments were formed. Dynamothermal metamorphic processes were responsible for the mobilization, concentration and deposition of the uranium and thorium in the adjacent units, and this led to the formation of the deposits.

(6) The localization of the uranium deposits only in the granodioritic granofels and in the migmatite rocks of the Charlebois Lake Complex is probably related to mechanical and chemical factors. It is assumed that the calc-silicate rocks were the key controlling factor for the trapping of the uraniferous solutions in the granodioritic granofels and in the migmatite, since the radiometric analyses showed that no relevant concentration of uranium minerals is found in the stratigraphically younger units of the

Charlebois Lake Complex.

Discordant fractures, compositional banding, crushed or brecciated zones are important physical properties of the calc-silicate rocks for emplacement of uranium.

The calc-silicate rocks in the Charlebois Lake area are instead considered to be too ductile for extensive fracturing, and bedding laminations are almost completely absent.

For this reason it is believed that they might have acted as a barrier against U migration.

(7) A study of the radioelement distributions in parts of the Charlebois Lake area not affected by the uranium mineralization can be greatly benefited in adding support to the conclusions proposed by this author, or in presenting new alternatives to the problem of the origin of the U deposits in the area. Such a study would require a larger number of samples to analyze, possibly collected on a grid pattern (at least in the granitic and tonalitic gneiss) and this would have extended the project well beyond the time available for this research.

CHAPTER VII

COMPARISON OF THE CHARLEBOIS LAKE URANIUM DEPOSIT WITH SIMILAR DEPOSITS ELSEWHERE

Introduction

In contrast to occurrences of uraninite in intrusive pegmatites, which is relatively common, disseminated uraninite in metasedimentary syngenetic pegmatites, migmatites and other metamorphic rocks is not as common and, because of the general poor interest in these low-grade uranium deposits until five years ago, they remained mostly undetected. The reasons why these deposits deserved little attention are also due to specific problems, such as: (i) The difficulty, expense and time involvement in the exploration for low-grade deposits. (ii) The difficulty of grade determination (large bulk samples may be the only accurate method for determining grade). (iii) The difficulty of drilling low-grade uranium deposits where it may prove necessary to contain, recirculate, and sample drilling water (uranium being easily soluble in water can be leached from the core or chips and from the walls of the hole).

Only very recently geologists started looking for this type of uranium deposit, as a consequence of the growth in the demand for uranium and constant increasing prices of U_3O_8.

The economics of the electrical utilities industry indicate that most of the future large generating plants

will use nuclear fuels. This use will increase the annual world uranium demand 12-to 15-fold by the year 2000 (Williams, 1976).

In response to this increasing demand, annual production capacity will grow to 44,000 tons of uranium by 1978 and to 90,000 tons by 1985 (Williams, 1976).

To support this anticipated uranium production beyond the early 1980's, it seems that the uranium industry should search for large-tonnage, low-grade uranium deposits.

The average grade of uranium ore mined today is about 0.24% U_3O_8, and is recovered mainly from relatively high-grade sandstone-, conglomerate-, and vein-type deposits. This is forecast to drop to about 0.04% in the next 25 years (Armstrong, 1974), and therefore low-grade, large-tonnage deposits will become the chief source of the world's future uranium supply.

One evidence for the present economic potential of this type of uranium deposit is given by the Rössing Deposit, South West Africa (Fig. 18). Uranium was first found at Rössing in 1928; intense prospecting was carried on during the period 1955-1958; recognition of its potential as a large low-grade deposit was in 1970, and production is scheduled to begin in 1976 or 1977.

This deposit has been selected by this writer to be compared with the Charlebois Lake deposit, on the basis of petrographic and mineralogic analogies between the two.

The other deposits that will be compared with the Charlebois Lake deposit are those of the Wheeler Basin, in Colorado.

The Rössing Uranium Deposit

The Rössing uranium deposit is located in the Namib desert, about 63 km northeast of Swakopmund, South West Africa. It occurs in a migmatite zone in which uraniferous, alaskitic granite/pegmatites and metamorphosed country rock show concordant, discordant and gradational relationships.

The rocks of the area have suffered dynamothermal and contact metamorphism, corresponding to the upper amphibolite facies of a Barrovian type.

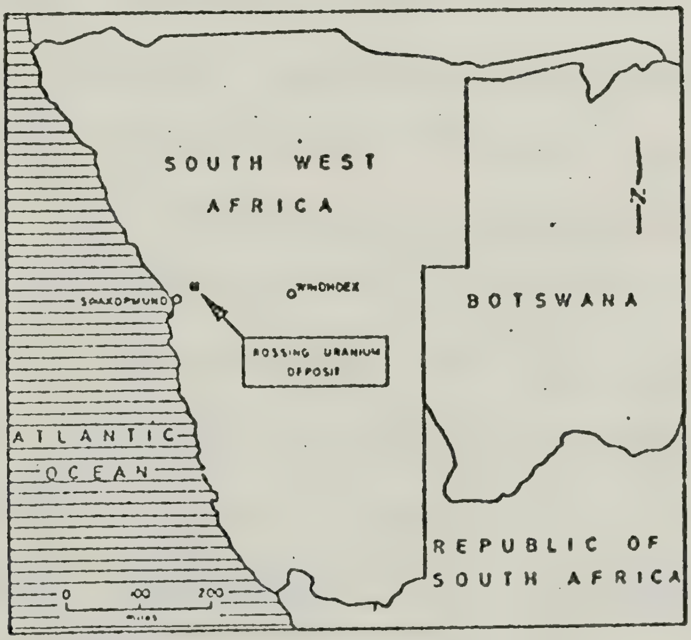


Fig.18. Locality plan of Rössing uranium deposit (after Berning et al.,1976)

The bulk of the economic mineralization is contained in alaskite that is preferentially emplaced into a pyroxene-

garnet gneiss/amphibole unit and into an amphibole-biotite schist/lower marble/lower cordierite-biotite gneiss unit (Berning, et al, 1976).

Alaskite hosts all the primary uranium minerals and most of the secondary mineralization. Within the uraniferous zone enrichment is often noticeably present along biotite-rich selvages of the alaskite.

Uraninite is the dominant primary radioactive mineral, occurring as grains a few microns to 0.3 mm in diameter. Uraninite is included in quartz, feldspar and biotite, and also as discrete grains interstitial to these minerals or along cracks between them. Alteration halos around the uraninite grains are common.

Betafite is also present and weathered outcrops contain secondary uranium minerals.

Zircon, apatite, and sphene are commonly associated with the radioactive minerals. Pyrite, chalcopyrite, molybdenite and ilmenite intergrown with magnetite are present in minor amounts.

Uraninite, betafite and biotite from the host rocks have all been dated as 510 $\pm$ 40 million years old.

The deposit contains in excess of 100 million tonnes of 0.05% U_3O_8. Rössing is to start production shortly, reportedly at 40,000 tonnes of ore per day.

Wheeler Basin, Grand County, Colorado

The Wheeler Basin is located about 8 km southeast of

Monarch Lake, Colorado.

The uranium occurrence is within Precambrian metamorphic rocks consisting of migmatized gneiss, mixed gneiss, and pegmatites.

An intrusion of Precambrian (Silver Plume) granite lies within 120 m of the occurrence and this ranges from granodiorite to granite, averaging quartz monzonite in composition.

Disseminated uraninite is confined to parts of the host rich in biotite. These uraninite-bearing biotite concentrations are very radioactive (Young and Hauff, 1975).

Encrustations of uranophane are seen on books of biotite on the outcrop. Zircon, molybdenite, chalcopyrite, hematite, pyrite and monazite are commonly disseminated as small grains and crystals within the radioactive zones. Uraninite is the dominant primary radioactive mineral, often occurring in a well-developed cubic habit, generally from 0.1 to 0.3 mm across.

The origin of the uraninite disseminations is attributed by Young and Hauff (1975) to remobilization and concentration of elements during metamorphism caused by the intrusion of the Silver Plume Granite [Quartz Monzonite].

The deposit has not been studied in terms of its economic potential. It has been reported to have as much as 0.73% U_3O_8 in limited quantities, whereas tonnages in terms of 0.05% U_3O_8 are not estimated (Young and Hauff, 1975).

A comparison of the Rössing deposit and the occurrences in the Wheeler Basin with the Charlebois Lake deposits shows more similarities than differences. The characteristics of the three deposits are presented in Table XX.

Other Low-Grade Uranium Deposits

Other low-grade uranium deposits showing some similarities to the Charlebois Lake deposit, in terms of host-rocks, mineralogy, and distribution of uranium minerals, are in the "Crocker Well" deposits of southern Australia, and the "Big Meadow" deposit at Bear Lake, Valley County, Colorado.

The radioactive mineral in the Crocker Well deposits is absite, a complex uranium-thorium-titanate which contains 32% U_3O_8. Adamellite, alaskite, and alaskite pegmatite are the host rocks for the radioactive deposits. The average grade is between 0.05% and 0.07% U_3O_8 (Armstrong, 1974).

The Big Meadow deposit is characterized by radioactive black minerals (principally euxenite), occurring in quartz monzonite and quartz diorite which are cut by a network of aplite and pegmatite dykes and stringers (Armstrong, 1974).

According to Geoffroy and Sarcia (1960), the "pegmatites" of the Charlebois Lake area are comparable to occurrences in the Ekomedion district, Cameroon. Unfortunately insufficient information is presently available with regard to the Ekomedion district, to test if analogies exist with the Charlebois Lake deposit and to what degree.

TABLE XX

Comparison of the Charlebois Lake Uranium Deposit with the Rössing Deposit and the Wheeler Basin Occurrence

	Rössing Deposit	Wheeler Basin	Charlebois Lake
Host rock	Pegmatite and metamorphic rocks	Metamorphic rocks and pegmatite	Metamorphic rocks
Grain size (rock)	1-5 mm	less than 1-5 mm, rarely larger	5 mm, often larger
Mineralogy: Primary	Quartz	Quartz	Quartz
	Plagioclase	Plagioclase	Plagioclase
	Microcline	Microcline	Microcline
	Biotite	Biotite	Biotite
		Sillimanite	Sillimanite(rare)
		Muscovite	Muscovite
	Uraninite	Uraninite	Uraninite
	Betafite		Betafite(?)
			Thucolite
	Davidite		
	Monazite	Monazite	
	Zircon	Zircon	Zircon
	Pyrite	Pyrite	Pyrite
	Chalcopyrite	Chalcopyrite	
			Pyrrhotite
	Molybdenite	Molybdenite	Molybdenite
	Ilmenite	None(?)	Ilmenite (rare)
	Magnetite		Magnetite
	Fluorite (rare)	Fluorite (rare)	
	Hematite (rare)	Hematite	Hematite (rare)
Secondary	Uranophane	Uranophane	Uranophane
	Beta-uranophane		
	Metatorbernite		
	Metahaiweeite		
	Carnotite		Carnotite
		Curite	
		Chlorite	Chlorite
Uraninite habit and size	Cubes and grains few micrometres to 0.3 mm	Cubes and grains 0.1-0.3 mm	Cubes and grains few micrometres to 0.3 mm
Age	510 $\pm$ 40 m.y.	1450 $\pm$ 20 m.y.	1800 $\pm$ 50 m.y.(?)
Grade and tonnage	As much as 0.55% U in small and patchy amounts; > 100 million tonnes of 0.05% U	As much as 0.73% U in probably small amounts; tonnage in terms of 0.05% U is not known	As much as 0.55% U in very small and patchy amts. Several million tons, of 0.05% U(?)

Low-grade uranium mineralized areas showing some similarities with the Charlebois Lake uranium deposit also occur in the Laurentians and along the north shore of the Gulf of St. Lawrence, where uraninite, uranothorite and zircon are disseminated within pegmatite granite and in migmatites. Mineralization is often widespread over large distances at the surface, but grades over such distances rarely exceed 0.05% U_3O_8 (Baldwin, 1970).

Suggestions for Exploration

The result of this investigation suggests certain new approaches to uranium exploration.

The geological map of Canada shows numerous target areas, in accordance with the petrographic characteristics of the deposits discussed in the previous paragraph, independently from the conditions of uranium emplacement.

The following suggestions are tentatively recommended:

(1) Knowledge of the regional distribution of uranium possibly based on different types of regional ground geochemical and airborne geophysical surveys.

(2) Selection of an area with a likely source for uranium: rocks of granitic composition being probably the most favourable in the Canadian Shield, where they commonly occur over large areas, and sometimes they exhibit anomalously high uranium concentrations. These uranium

"highs" in granitic rocks produce, in many cases, a visible pale-yellow staining (gummite) on the rock-surface. The radiometric response, in terms of counts per second with the scintillometer, is of the order of 400 c.p.s. using the SRAT SPP2, and of 600 c.p.s. using the Scintrex BGS ISL.

(3) Airborne gamma spectrometric surveys, preferentially multichannel, may be helpful in defining areas for exploration or land acquisition. However, problems already discussed in Chapter V concerning soil cover, typical leaching of uranium near the surface and rugged topography may invalidate this type of survey. As an alternative, or in conjunction with the airborne gamma-ray survey, one or more of the following studies are recommended, depending on the type of terrain, vegetation, climate, and topography:

(i) Radon emanometry, track-etch surveys (Gingerich, 1974).

(ii) Geochemical prospecting using soil, stream, or lake sediment samples. Because of the high mobility of uranium in the oxidized (U^{6+}) state, it can move large distances in the surficial environment, making possible regional surveys of large tracks of land. Major geochemical provinces or larger near-surface uranium deposits may be outlined

with lake water or sediment sample densities as low as one per 10 square miles (Dyck, 1975).

(iii) Biogeochemical surveys.

(4) The prospect areas should also contain metasedimentary rocks suspected to possess favourable physical and chemical properties. It has been postulated by this author that the calc-silicate rocks may be considered as "favourable" rocks, although it has not been fully documented or proven.

Whilst the potential source area in isolation might or might not contain sufficiently large low-grade concentrations to be economically interesting, the existence of both potential source area and geologically favourable metasedimentary rock-types would represent a much more attractive situation for uranium exploration.

As the source area is identified and the geologically favourable surroundings found, then the next phases of exploration require the usual detailed geological and radiometric survey procedures.

CHAPTER VIII

CHARLEBOIS LAKE URANIUM DEPOSITS: CONCLUSIONS

The following conclusions may be drawn from the results of the field and laboratories studies.

(1) Large bodies of low-grade uraniferous rocks are present in the area. All the principal radioactive showings occur within granodioritic granofels and in migmatites.

(2) Uraninite is the principal uraniferous phase present in the rocks of the thesis area. It occurs as isolated, subhedral to euhedral grains, mostly associated with aggregations of biotite. Thucolite, a carbon-bearing uranium minerals, has been detected in one sample. Secondary uranium minerals include uranophane and probably betafite.

(3) Minor amounts of molybdenite, magnetite, pyrite and pyrrhotite occur in the rocks. The molybdenite does not constitute an economically viable commodity.

(4) A study of the radioelements distribution in the Charlebois Lake deposits shows that:

(i) All the rocks of the complex are enriched in U above normal metamorphic rocks by at least a factor of three and in Th by at least a factor of one and a half, with the

noted exception of the granitic and tonalitic gneisses which show normal Th concentrations. None of the rocks of the complex exhibit anomalous K values.

(ii) Some U and Th mobilization and redistribution probably took place within the complex. U and Th migration may have occurred prior or during regional metamorphism. The redistribution of U was not coeval with K migration, or at least, U did not behave in the same manner as K, as the lack of U-K correlation shows.

(iii) The granitic and tonalitic gneisses of the area constitute the most likely source-rocks of the uranium deposits.

(5) Very large increases in reserves are required to meet the constant rising uranium demand beyond 1980. As the commodity becomes in short supply it seems logical that uranium industry should search for large-tonnage, low-grade deposits, such as the Charlebois Lake. One example of the present economic potential of this type of uranium resource is given by the Rössing deposit, in South West Africa. A comparison of this deposit with the Charlebois Lake deposit and another similar uranium occurrence, the Wheeler Basin of Colorado, shows many similarities and a model

for new approaches to uranium exploration been tentatively forwarded.

PHOTOGRAPHIC PLATES

LEGEND TO PLATE I

a: Sericite-biotite-diopside gneiss ("Cathy's" showing).

b: Boudinage of quartz and microcline in tonalitic gneiss. (south of Dramnitzke Bay).

c: Skialiths rafts of mafic material in granitic gneiss.(north of Machete Lake).

d: Possible original bedding in biotite gneiss. (Dramnitzke Bay).

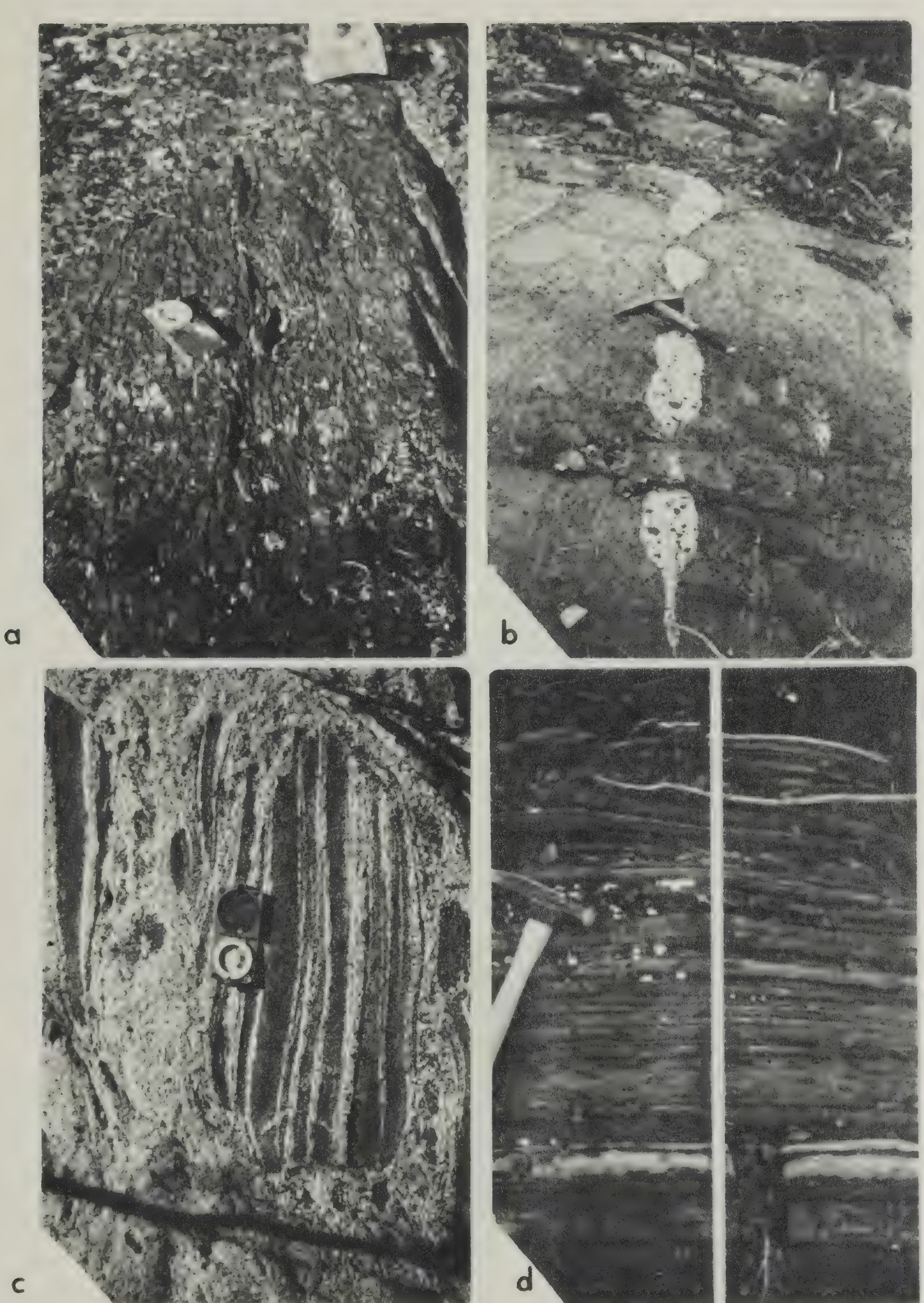

a b c d

PLATE I

LEGEND TO PLATE II

a: Migmatite: felsic intercalating bands (granitic composition) in the biotite gneiss. Migration of the felsics is visible. ("Row" showing).

b: Parasitic microfolds of microcline in the biotite gneiss. (Nose of the Pegasus Lake antiform).

c: Instrusive contact between cross-cutting pegmatite dyke and a biotite gneiss. (Dramnitzke Bay).

d: Amphibolite band in tonalitic gneiss. Notice the fracture in the amphibolite, filled with remobilized granodioritic material. (Dramnitzke Bay).

PLATE II

LEGEND TO PLATE III

a: Tight folding in the migmatite (nose of the Pegasus Lake antiform).

b: Migration of granodioritic material (mainly K-feldspar microcline) within the migmatite. (nose of the Pegasus Lake antiform).

c: Conformable amphibolite layer in granitic gneiss. (nose of the Pegasus Lake antiform).

d: Pionjar drilling in trench "A", in U.R. showing. (Charlebois Lake).

a

b

c

d

PLATE III

PHOTOMICROGRAPHS

All the photomicrographs presented in the following plates have been taken with cross-nichols, except where otherwise specified.

LEGEND TO PLATE IV

a: Sample #11 Deformed plagioclase in very coarse-grained porphyroblastic biotite-rich pegmatite. (Chestnut Lake).

b: Sample #20 Concentric cracks around metamict zircon in plagioclase in biotite plagioclase-quartz diorite. ("CAM" showing).

c: Sample #99 Highly deformed biotite in plagioclase biotite-rich pegmatite. (Chestnut Lake).

d: Sample #14 Serpentine (S), Carbonate (Ca), and talc (Ta) in talc-serpentine marble. (ophicalcite). ("CAM" showing).

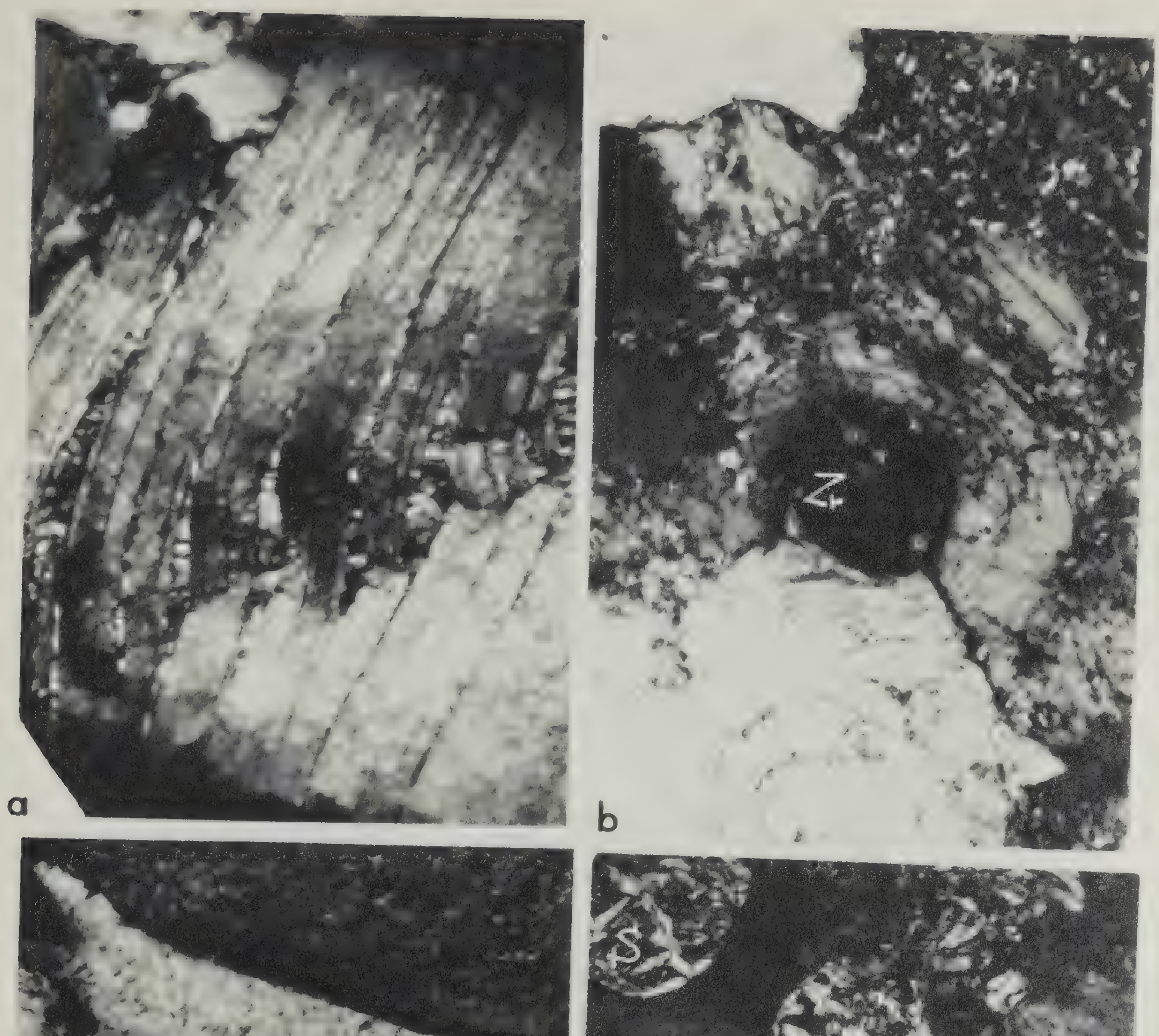


PLATE IV

1/4 mm

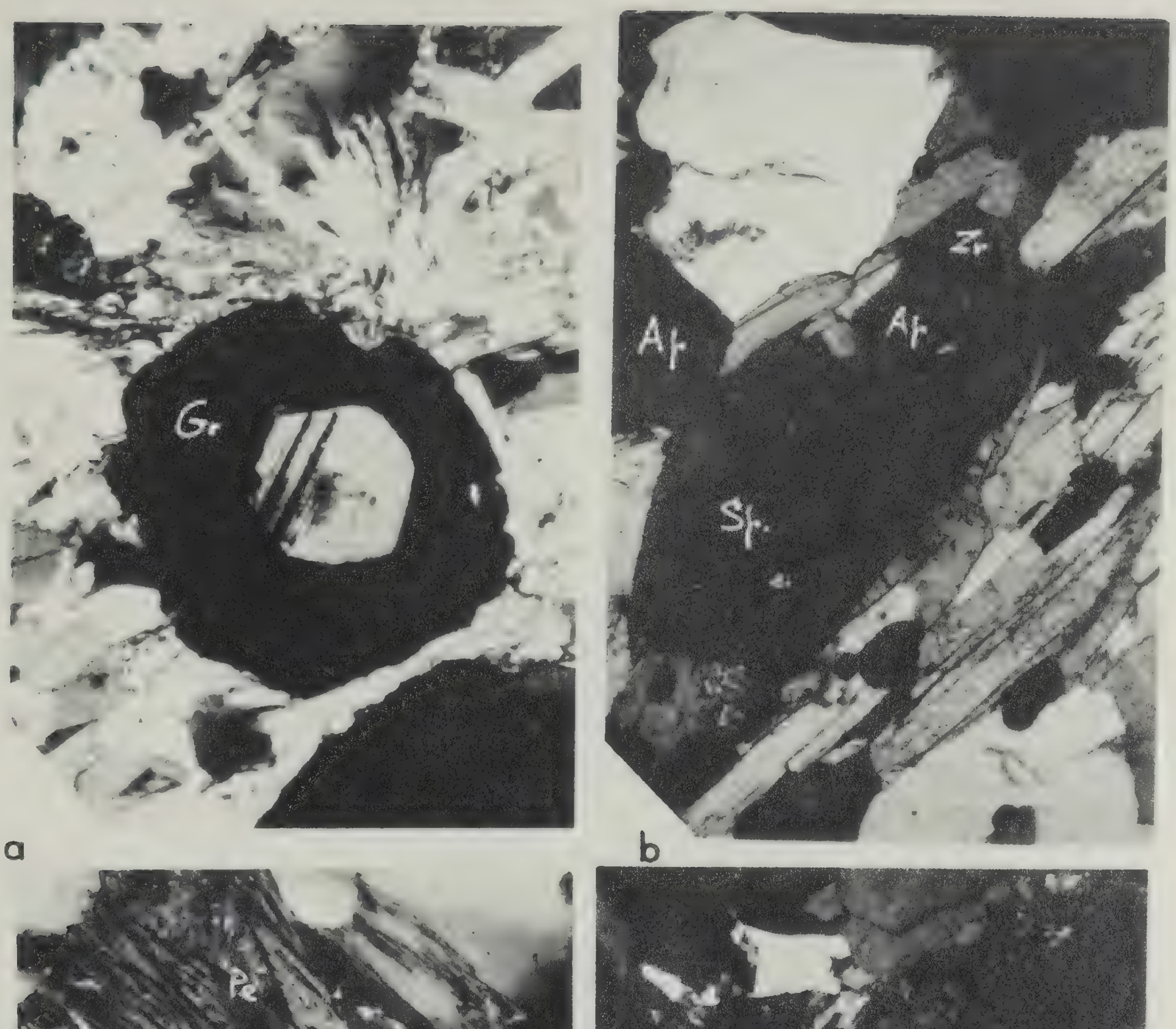
LEGEND TO PLATE V

a:	Sample #97	Uraninite and zircon in quartz and biotite in biotite microcline-rich portion of a migmatite. (Chestnut Lake). Uraninite = U; Zircon = Zr.
b:	Sample #65	Apatite (ap) and metamict zircon (Zr) in the biotite in sphene-biotite microcline-plagioclase gneiss. ("Row" showing).
c:	Sample #18	Fine-grained biotite plagioclase gneiss. ("Row" showing).
d:	Sample #80	Banded sillimanite-biotite-plagioclase-microcline gneiss with incipient migmatization. ("Row" showing).

PLATE V

LEGEND TO PLATE VI

a:	Sample #1	Sillimanite (Si), garnet (Gr), muscovite (Ms), biotite (B) in medium and fine-grained banded sillimanite-muscovite-garnet-biotite gneiss, with incipient migmatization. ("Row" showing).
b:	Sample #65	Sphene (Sp), metamict zircon (Zr), and apatite (Ap) in sphene-biotite microcline-plagioclase gneiss. ("Row" showing).
c:	Sample #82	Biotite grain, almost completely altered to pennine (Pe) and sericitized plagioclase in plagioclase-rich granodioritic granofels. ("Row" showing).
d:	Sample #13	Chloritization of biotite caused by deformation in very coarse-grained biotite microcline-rich granodioritic granofels. (Higginson Lake).



a b c d

PLATE VI

1/4 mm

LEGEND TO PLATE VII

a:	Sample #98	Granulated quartz and K-feldspar in microcline-rich portion of a migmatite. (Chestnut Lake).
b:	Sample #11	Recrystallized quartz showing fluidal texture and bent plagioclase in cataclastic coarse-grained porphyroblastic biotite-rich granodioritic granofels. (Chestnut Lake).
c:	Sample #26	Myrmekitic textures in saussuritized plagioclase in medium and coarse-grained biotite plagioclase-microcline granitic gneiss. (3000 m south of Chestnut Lake).
d:	Sample #1	Biotite grain with haloes around metamict zircons in medium and fine-grained, banded sillimanite-muscovite-garnet-biotite gneiss, with incipient migmatization. ("Row" showing).

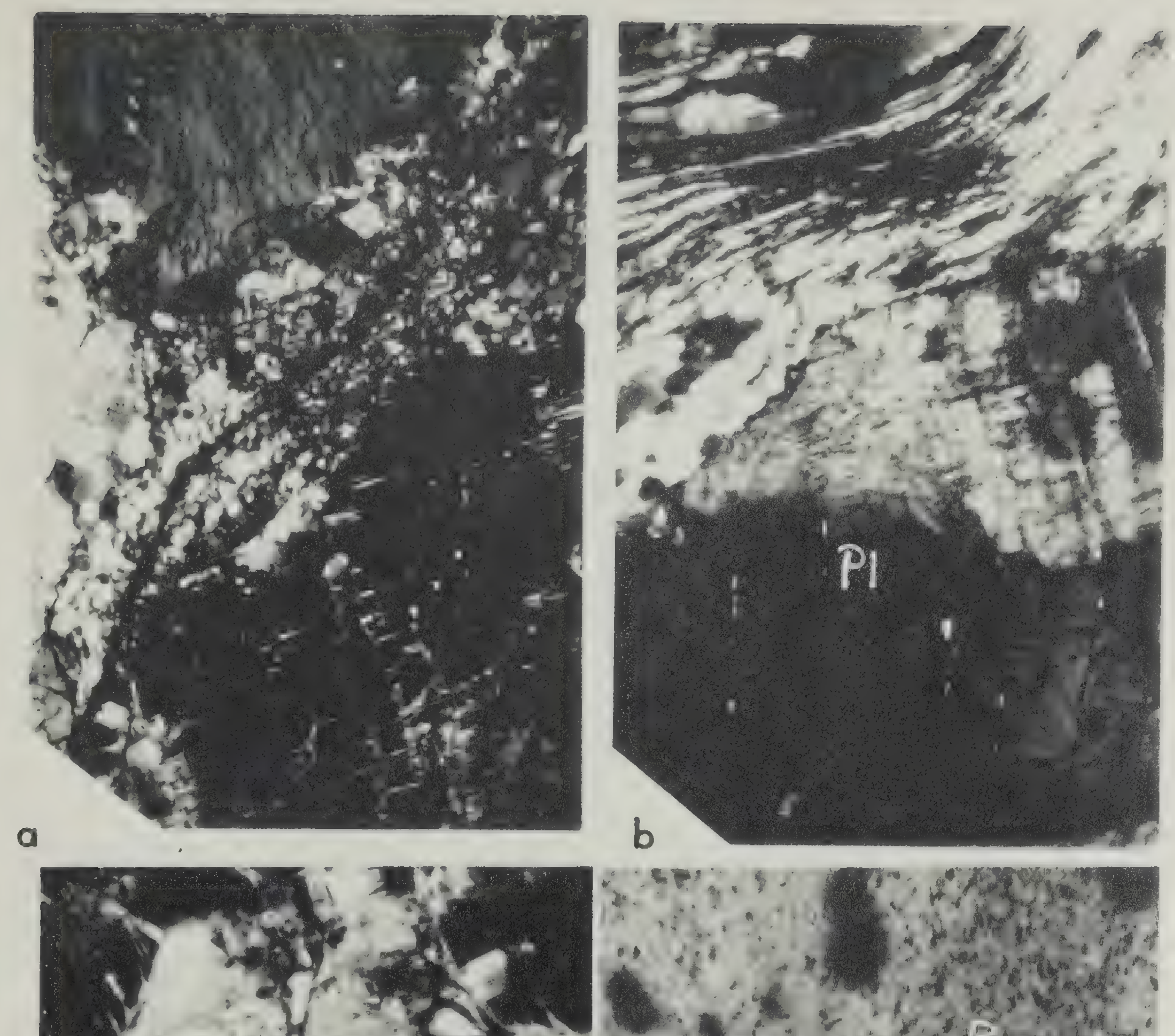


PLATE VII

1/4 mm

LEGEND TO PLATE VIII

a:	Sample #36	Sillimanite (Si), muscovite, (Ms), biotite (B) in sillimanite-muscovite-biotite-plagioclase-microcline gneiss with incipient migmatization. ("Row" showing).
b:	Sample #68	Diopside (Di), and hornblende (Hb), showing a mosaic texture in very fine-grained cummingtonite-hornblende-diopside-calc-silicates. ("Cathy's" showing).
c:	Sample #2	Poikiloblastic diopside (Di), phlogopite (Ph), sericite (Se) in porphyroblastic fine-grained sericite-phlogopite-diopside gneiss. (Charlebois Lake).
d:	Sample #76	Diopside in the corners of the microphotograph (Di) in tremolite-bearing diopside crystal. Rice-like and fibrous textures in tremolite (Tr). ("Row" showing).

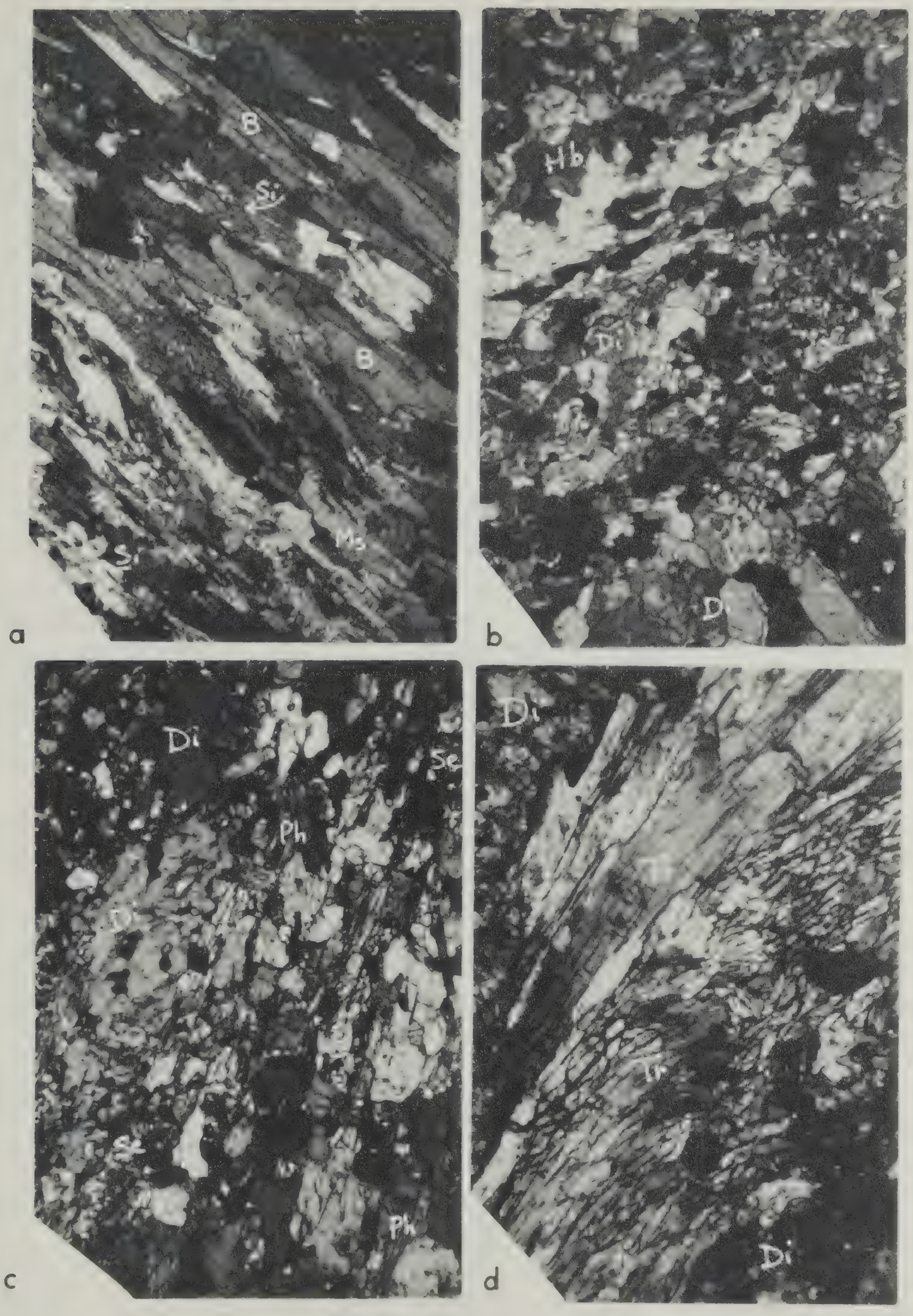


PLATE VIII

LEGEND TO PLATE IX

a:	Sample #44	Fine-grained banded amphibolite. (Dramnitzke Bay).
b:	Sample #100	Tourmaline (To) with quartz in tourmaline plagioclase-rich pegmatite. (Chestnut Lake).
c:	Sample #228	Garnet quartz-rich portion of a biotite migmatite. Garnet (Gr), biotite (Bi). ("Dianne" showing - Higginson Lake area).
d:	Sample #85	Serpentine-talc-diopside marble. Diopside (Di), carbonate (Ca), serpentine (Se). Notice the coarse, highly fractured diopside grain with inclusions of irregular serpentine grains. ("Row" showing).

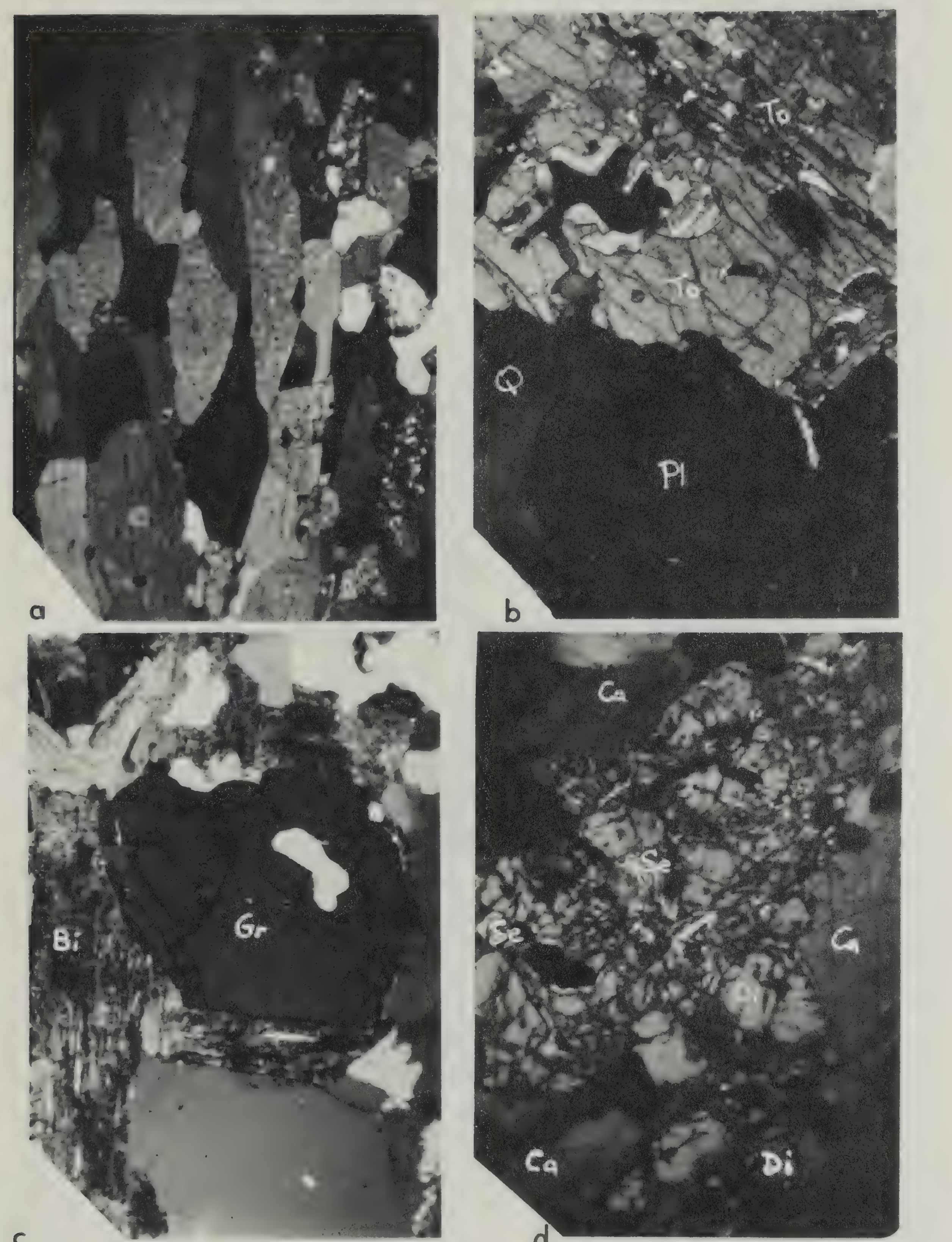


PLATE IX

LEGEND TO PLATE X

a:	Sample #24	Uraninite in biotite in muscovite-biotite microcline-rich granodioritic granofels. Notice the cracks and the halo around the uraninite, produced by radioactivity. (Charlebois Lake).
b:	Sample #233	Pleocroic halo in quartz produced by uraninite. Uraninite grains are almost completely destroyed - cause, oxidation and weathering. (Guppy Lake area).
c:	Sample #211	Small uraninite cube in quartz in a medium grained muscovite-biotite plagioclase-microcline granitic granofels. (Higginson Lake area).
d:	Sample #233	Well preserved uraninite cube in biotite. It is also evident the absence of distortion in the biotite cleavage plans. (Guppy Lake area).

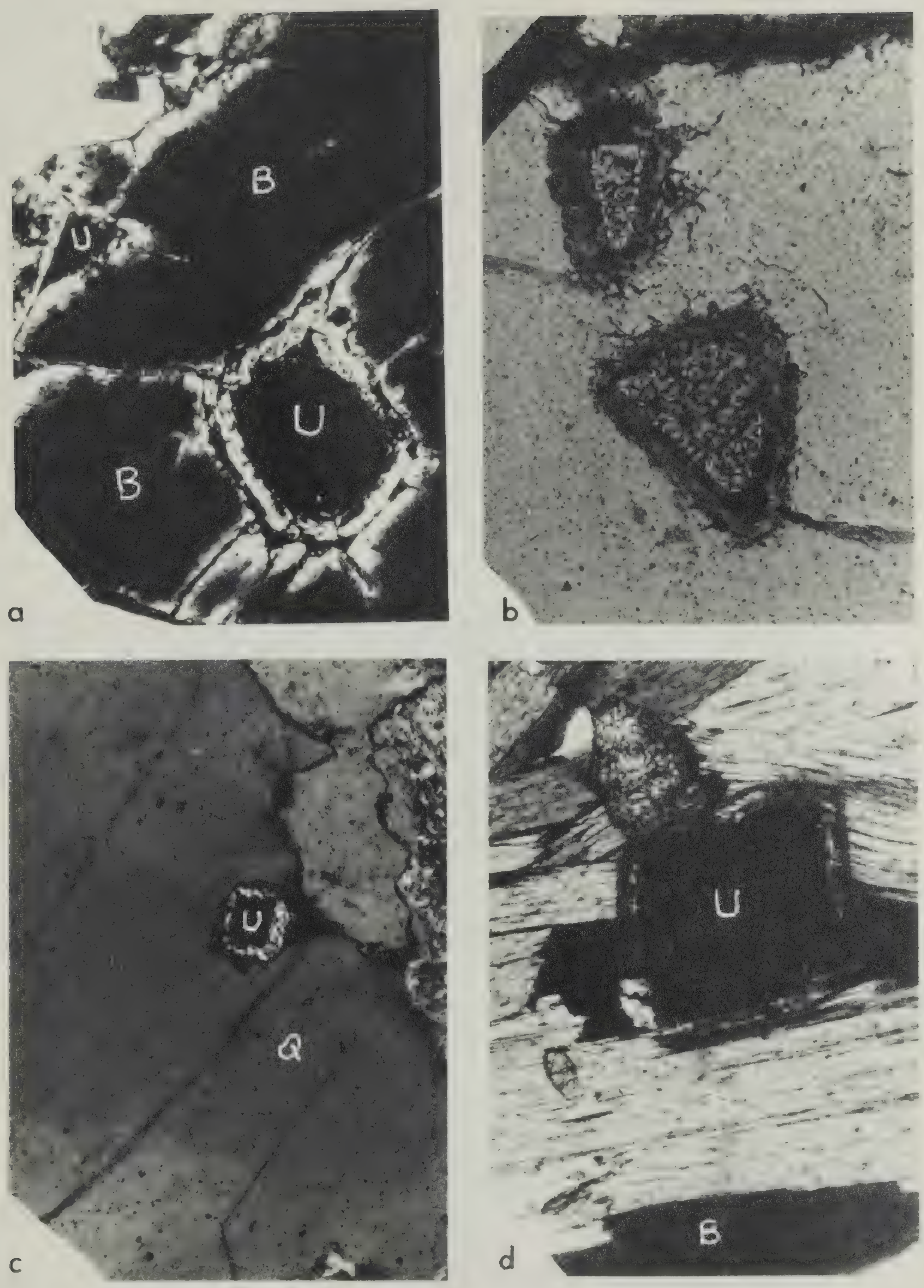


PLATE X

1/4 mm

LEGEND TO PLATE XI

a:	Sample #231	Euhedral uraninite crystals in plagioclase, in a coarse-grained biotite microcline-plagioclase granodioritic granofels. (Guppy Lake area). (Enlarged 40 times).
b:	Sample #231	Same as above, enlarged 160 times. Secondary uranium minerals form light rims around uraninite.
c:	Sample #155	Anhedral grains and cubic crystals of uraninite in quartz and in biotite, in a coarse-grained muscovite-biotite plagioclase-microcline granitic granofels. (Bell Lake area). (Enlarged 40 times).
d:	Sample #155	Same as above, enlarged 160 times.

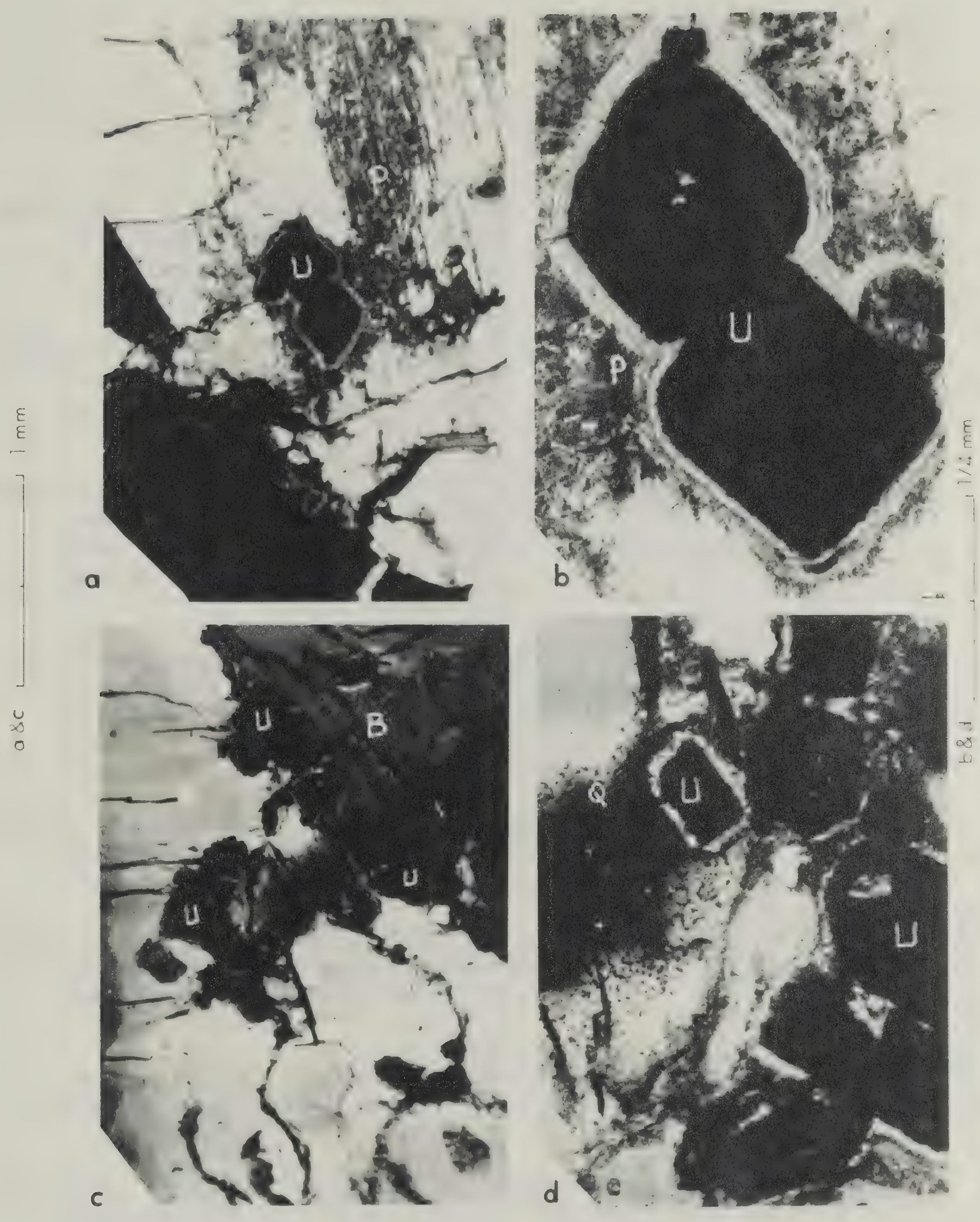


PLATE XI

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APPENDIX I

Thin section descriptions of the most representative samples studied.

THIN SECTION DESCRIPTIONS

SAMPLE NO. 1

A. Texture:

a) Grain size: medium to fine-grained.

b) Orientation: good parallel orientation of biotite.

c) Grain development: granular hypidiomorphic. Gneissic texture, diffuse banding. Mostly euhedral biotite, feldspars anhedral, garnet anhedral, rounded.

d) Post-crystalline deformation: absent.

B. Minerals:

- Quartz: very irregular grains, with embayed boundaries and undulose extinction. Uniformly distributed. Some grains are elongated and parallel oriented.
- Plagioclase: andesine; twinning is poorly represented. Alteration is present. Myrmekitic textures are common. Zonation of the grains was found.

- Microcline: fresh, irregular grains, with good twinning. Perthites are very common and they show different shapes: beads, stringlets, rod, patches. Undulose extinction is sometimes visible.
- Biotite: aggregates of several intergrowths, segregated in bands. Pleochroism: from very pale brown to medium-rusty brown. Numerous metamict zircons are present as inclusions showing pleochroic radio-active haloes around the grains.
- Muscovite: aggregates of several small elongated lamellae, subhedral, with sharp lateral boundaries and irregular, sometimes ragged edges.
- Garnet: very coarse, mostly rounded grains, highly fractured, with numerous biotite inclusions. (Plate VIa).
- Accessories: sillimanite, metamict zircon.
- Secondary minerals: very little biotite, as alteration product from biotite and garnet.
- Quantitative composition: se modal analyses.
- Name of the rock: medium and fine-grained banded sillimanite-muscovite-garnet-biotite gneiss with incipient migmatization.

SAMPLE NO. 99

A. Texture:

a) Grain size: coarse, with fine recrystallized quartz.

b) Orientation: very slightly present due to the biotite segregated in sub-parallel bands.

c) Grain development: mostly anhedral, with some subhedral biotite. Quartz is almost completely new, recrystallized after cataclastic deformation, with mechanical fragmentation and recrystallization of the grains. Biotite is highly bent, and partly crushed. Plagioclase is also bent.

d) Post-crystalline deformation: Cataclasis is evident and affected all the minerals of the rock.

B. Minerals:

- Quartz: sutured boundaries and very common growth-mosaic sub-textures. The grains are elongated. Undulose extinction.

- Plagioclase: andesine, very coarse, rounded grains, bordered by biotite and weakly altered. Post-crystalline deformation affected in part the plagioclase: bent lamellae are visible, slightly broken and filled by recrystallized quartz.
- Biotite: aggregates of several intergrowths, elongated, bent, broken and stretched. Pleochroism: from medium brown to deep brown.
- Accessories: pyrite, hematite and apatite.
- Secondary minerals: chlorite, as alteration product of the biotite.
- Estimate of quantitative composition: Quartz 35%, biotite 35%, plagioclase 30%.
- Name of rock: biotite-rich tonalitic granofels.

SAMPLE NO. 93

A. Texture:

a) Grain size: medium and coarse grained.

b) Orientation: biotite sub-oriented.

c) Grain development: granular allotriomorphic, with euhedral to subhedral biotite, and felsic minerals, anhedral. Quartz presents sutured boundaries, mosaic intergrowths sub-textures.

d) Post-crystalline deformation: Quartz is the only mineral definitely showing the effects of the dynamic metamorphism: the fine-grained, recrystallized quartz has a preferential orientation of the grains. Biotite does not show any evident post-crystalline deformation.

B. Minerals:

- Quartz: the "old" quartz occurs as very irregular, coarse and fractured grains, with a strong undulatory extinction. Very fine-grained granulated quartz grains are due to a mechanical fragmentation. "New" recrystallized quartz shows alongated grains, with growth-mosaic sub-textures, and fluidal texture particularly well developed.

- Microcline: coarse to very coarse grains, often fractured and strained. Twinning is very common. Bent lamellae and weak undulatory extinction of some grains are possibly due to the post-crystalline deformation. Perthites are very common and plagioclase inclusions are always highly altered and are definitely partly replaced by microcline.
- Plagioclase: andesine. The grains are very irregular, often highly altered. Myrmekites are very common. Some grains show a reaction rim (zonation). It is partly replaced by microcline. Epidote is always found as inclusion and it is an alteration product from the plagioclase.
- Biotite: is present either as separate grains or in aggregates of several intergrowths, very weakly oriented. The isolated grains are usually irregular, whilst the aggregated grains are subhedral or euhedral. Pleiochroism: from pale brown to rusty brown. Numerous metamict zircon inclusions are visible, with their characteristic pleochroic haloes. Apatite

inclusions are also diffuse. Biotite is partly altered to chlorite.

- Accessories: Fe-oxides, metamict zircon, apatite, epidote, rutile, magnetite, (uraninite?).
- Secondary minerals: Chlorite, carbonates, muscovite.
- Estimate of quantitative composition: Microcline 40%, quartz 30%, plagioclase 23%, biotite 7%.
- Name of rock: microcline-rich portion of a biotite migmatite.

SAMPLE NO. 44

A. Texture:

a) Grain size: fine grained.

b) Orientation: excellent parallel orientation of the hornblende.

c) Grain development: granular hypidiogramorphic. Euhedral to subhedral hornblende. Anhedral the felsic minerals.

d) Post-crystalline deformation: absent.

B. Minerals:

- Plagioclase: andesine-labradorite. The grains are small, irregular, with embayed boundaries and diffusely altered to sericite. Twinning is poorly represented.
- Hornblende: usually found in aggregates, with the grains showing characteristic cleavage planes. Hornblende grains are fresh, aligned. Grain boundaries are sometimes embayed, especially when in contact with plagioclase. Pleochroism: from pale green to deep-olive green. Numerous round plagioclase grains are present as inclusion.
- Accessories: sphene, apatite.

- Secondary minerals: sericite.
- Quantitative composition: see modal analyses.
- Name of rock: fine-grained banded amphibolite.

SAMPLE NO. 34

A. Texture:

a) Grain size: from coarse to fine-grained.

b) Orientation: not ascertainable.

c) Grain development: diopside anhedral to subhedral, tremolite subhedral. Porphyroblastic, matrix unequigranular.

d) Post-crystalline deformation: absent.

B. Minerals:

- Diopside: is present as coarse, heavily fractured porphyroblasts, partly altered to tremolite and, in minor amounts, to sericite, especially along the borders. One section of the specimen shows smaller diopside grains, mostly equigranular, rounded and forming a mosaic texture. Pleochroism is absent.
- Tremolite: is found in fine-grained elongated aggregates. Pleochroism is absent.
- Accessories: sphene.
- Secondary minerals: calcite, phlogopite.

- Estimate of quantitative composition: diopside 75%, tremolite 25%.
- Name of the rock: porphyroblastic tremolite-diopside calc-silicate.

SAMPLE NO. 2

A. Texture:

a) Grain size: fine-grained.

b) Orientation: alternating bands (1 - 3 mm thick) of sub-oriented phlogopite and diopside-rich material.

c) Grain development: porphyroblastic. Part of the specimen is formed by round equidimensional grains, with a good mosaic texture. Mostly euhedral phlogopite, subhedral to anhedral diopside, anhedral plagioclase.

B. Minerals:

- Plagioclase: identification of the An content is not certain because of the common alteration of the plagioclase to sericite. It is possibly an andesine. The grains are very small and almost completely altered.
- Diopside: large grains, slightly elongated parallel to the foliation (and banding) of the rock. Finer grains are usually round. The margins are embayed and the grains very fractured. One particularly

coarse grain shows undulose extinction. Poikilotic textures are common. Pleochroism is absent.

- Phlogopite: found as aggregates of several intergrowths, segregated in bands. The grains are sometimes bent. Pleochroism: from very-pale-brown to medium-pale-brown.
- Sericite: very fine grained. Alteration product of the plagioclase.
- Accessories: apatite, sphene.
- Secondary minerals:
- Quantitative composition: see modal analyses.
- Name of the rock: porphyroblastic fine-grained sericite-phlogopite-diopside gneiss.

SAMPLE NO. 12

A. Texture:

a) Grain size: coarse-grained.

b) Orientation: not ascertainable.

c) Grain development: euhedral to subhedral biotite, subhedral to anhedral plagioclase, the rest of the felsics, anhedral.

d) Post-crystalline deformation: absent or very slight..

B. Minerals:

- Quartz: very coarse, irregular grains, uniformly distributed and showing undulose extinction. Small grains are also present especially along the boundaries with other grains, showing growth-mosaic subtextures (recrystallized quartz?). Very small fractures cut the coarser grains. Small equidimensional rounded blebs of quartz are often present as inclusion in the feldspars.

- Plagioclase: oligoclase-andesine. Very wide grain size range. Highly altered, partly replaced by microcline. Myrmekitic textures are very common.
- Microcline: very irregular grains, with a good twinning and grid structure. The grains are usually fresh, with numerous inclusions of quartz along the cleavage planes. (recrystallized quartz?). Undulose extinction is sometimes found.
- Biotite: mostly present as aggregates of several intergrowths oriented in random positions. Pleochroism is very strong: from medium brown to dark rusty-brown. Numerous inclusions are present: apatite and metamict zircon, with some radioactive haloes rounding the grains, are the most common inclusions. Iron-oxides are also common. Rutile needles are usually found along the biotite borders, where chloritization is stronger.
- Accessories: apatite, iron-oxides, Ti-minerals, metamict zircon.
- Secondary minerals: carbonates, chlorite.

- Quantitative composition: see modal analyses.
- Name of the rock: coarse-grained biotite microcline-plagioclase gneiss.

SAMPLE NO. 92

A. Texture:

a) Grain size: fine to medium-grained.

b) Orientation: not ascertainable.

c) Grain development: granoblastic polygonal, with decussate grain boundaries. The grains are mostly anhedral, with some subhedral microcline grains.

d) Post-crystalline deformation: very slight.

B. Minerals:

- Quartz: very irregular and inequidimensional grains, with decussate grain-boundaries. Undulose extinction.
- Plagioclase: andesine-oligoclase, Irregular grains, poorly twinned. Alteration is common. Myrmekitic textures are common, especially in the highly altered grains.
- Microcline: mostly irregular grains, with some subhedral grains, showing excellent grid twinning. Perthites are very common. Some grains show undulose extinction.

- Biotite: usually separated grains, oriented in random positions. Bleaching and alteration to chlorite are commonly found. Pleochroism: very pale-green to rusty-brown. Inclusions of sphene and rutile are present.
- Accessories: sphene, epidote, rutile, Fe-oxides.
- Secondary minerals: carbonates, chlorite.
- Quantitative composition: see modal analyses.
- Name of the rock: fine and medium-grained biotite plagioclase-granitic gneiss.

APPENDIX II

List of the samples studied.

SAMPLES STUDIED

Sample No.	Rock Name
1*	Medium and fine-grained banded sillimanite-muscovite-garnet-biotite gneiss, with incipient migmatization.
2*	Porphyroblastic fine-grained sericite-phlogopite-diopside gneiss.
3	Very coarse-grained biotite quartz-rich pegmatite.
4*	Coarse-grained plagioclase-microcline granitic granofels.
5*	Fine and medium-grained, diffusely banded sericite-diopside gneiss.
5b	Fine-grained biotite-sericite plagioclase-microcline gneiss.
6	Coarse-grained biotite plagioclase-microcline granitic granofels.
7	Medium-grained alkali-feldspar granitic gneiss.
8*	Fine-grained biotite microcline-plagioclase gneiss.
9*	Coarse-grained biotite-rich portion of a migmatite.
10	Fine and medium-grained quartz diorite.
11	Coarse-grained porphyroblastic biotite microcline-plagioclase tonalitic granofels.
12*	Coarse-grained biotite microcline-plagioclase gneiss.
13*	Very coarse-grained biotite microcline-rich pegmatite.
13a	Muscovite microcline-rich portion of a biotite migmatite.

Sample No.	Rock Name
13b	Coarse-grained biotite microcline-plagioclase granitic granofels (uraninite bearing).
14*	Talc-serpentine marble (ophicalcite).
15	Medium-grained quartz-diorite.
16	Fine-grained amphibolite.
17*	Magnetite-biotite plagioclase gneiss with incipient migmatization.
18	Fine-grained biotite plagioclase gneiss.
19*	Biotite quartz-dioritic gneiss.
20	Biotite quartz-dioritic gneiss.
21*	Fine and medium-grained pyroxene-amphibolite.
22*	Fine-grained plagioclase hornblende-diopside calc-silicate.
23*	Fine-grained granodioritic gneiss.
24*	Coarse-grained muscovite-biotite plagioclase-microcline granitic granofels.
25	Coarse-grained magnetite-rich biotite plagioclase granodioritic granofels.
26*	Medium and coarse-grained biotite plagioclase-microcline granitic gneiss.
28*	Sericite hornblende gneiss.
29*	Medium-grained biotite microcline-plagioclase quartz-dioritic granofels.
30*	Fine-grained amphibolite.
31*	Quartz-rich portion of a biotite migmatite.
33*	Porphyroblastic diopside-hornblende gneiss (pyribolite).

Sample No.	Rock Name
34	Porphyroblastic tremolite-diopside calc-silicate.
35	Medium-grained biotite plagioclase-microcline granitic granofels.
36	Sillimanite-muscovite-plagioclase-microcline biotite.gneiss with incipient migmatization.
37	Sericite-diopside-actinolite microcline hornblende gneiss.
38*	Biotite microcline-plagioclase gneiss with incipient migmatization.
39	Medium-grained biotite plagioclase-microcline granitic granofels.
40*	Coarse and medium-grained plagioclase-microcline portion of a biotite migmatite.
41	Coarse-grained biotite microcline-plagioclase monzodioritic granofels.
42	Coarse-grained plagioclase-microcline granitic granofels.
43	Porphyroblastic tremolite-diopside calc-silicate.
43a	Fine-grained, banded hornblende-biotite plagioclase gneiss.
44*	Fine-grained, banded amphibolite.
45	Coarse-grained biotite plagioclase-microcline quartz-syenitic granofels.
46*	Biotite-rich portion of a magnetite quartz-microcline-plagioclase migmatite.
47*	Coarse-grained plagioclase-microcline quartz-monzonitic granofels.
48	Coarse-grained alkali-feldspar syenitic granofels (strained microcline).
50	Biotite plagioclase gneiss with incipient migmatization.

Sample No.	Rock Name
51	Biotite-rich portion of a quartz-plagioclase migmatite.
52	Medium grained sillimanite-apatite-biotite microcline-plagioclase tonalitic granofels.
53	Coarse-grained biotite plagioclase quartz-rich granitoidic granofels.
54*	Biotite-rich portion of a plagioclase-quartz migmatite.
55	Quartz-rich portion of a biotite migmatite.
56	Coarse-grained biotite microcline-plagioclase quartz-monzodioritic granofels.
57*	Biotite plagioclase-microcline granitic gneiss.
58*	Biotite microcline-plagioclase quartz-dioritic gneiss.
59*	Plagioclase-quartz-rich portion of a biotite migmatite.
60	Coarse-grained microcline-plagioclase granitic granofels.
61	Part of a quartz vein.
62	Fine-grained hornblende gneiss.
63*	Coarse-grained biotite plagioclase-microcline quartz-syenitic granofels.
64*	Biotite plagioclase-microcline gneiss with incipient migmatization.
65*	Sphene-biotite microcline-plagioclase gneiss.
66	Quartz-rich portion of a biotite migmatite.
67*	Quartz-rich portion of a biotite migmatite.

Sample No.	Rock Name
68	Very fine-grained cummingtonite-hornblende-diopside calc-silicate.
73	Coarse-grained plagioclase-microcline alkali-feldspar quartz-syenitic granofels.
74	Microcline-rich portion of a migmatite.
75	Microcline-rich portion of a migmatite.
76*	Tremolite-bearing diopside crystal.
77	Coarse-grained biotite plagioclase-microcline alkali-feldspar granitic granofels.
78	Muscovite-biotite plagioclase-quartz-rich portion of a microcline migmatite.
79*	Fine-grained banded biotite plagioclase gneiss with incipient migmatization.
80	Banded sillimanite-biotite plagioclase-microcline gneiss with incipient migmatization.
81	Medium-grained biotite microcline-plagioclase granodioritic granofels.
82*	Medium-grained biotite-rich tonalitic granofels.
84	Coarse-grained biotite microcline-plagioclase granitic granofels.
85*	Serpentine-talc-diopside marble.
86	Medium and coarse-grained microcline-rich portion of a migmatite.
87	Magnetite-biotite plagioclase-microcline monzonitic granofels.
88	Very coarse-grained plagioclase-rich pegmatite.

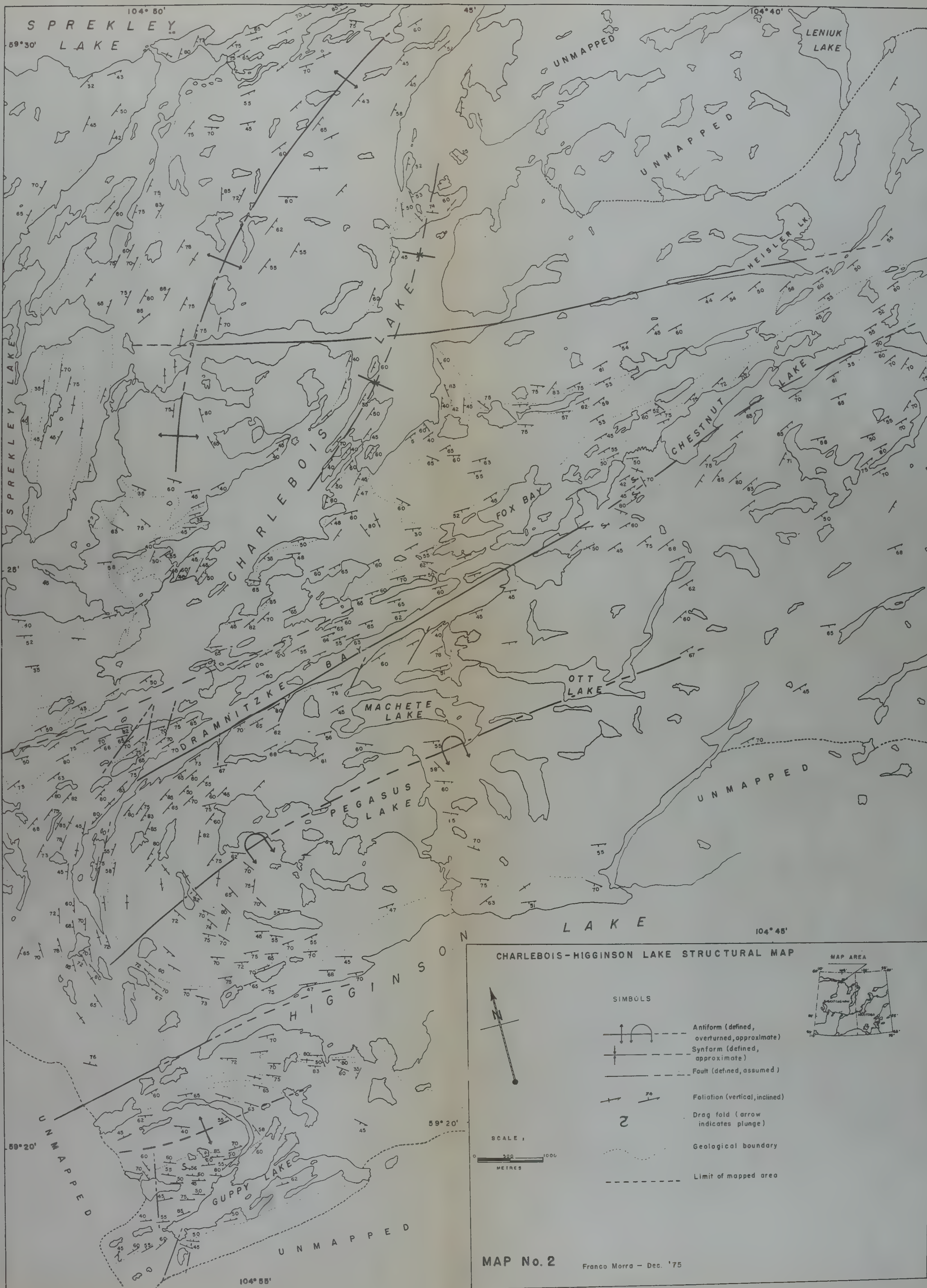
Sample No.	Rock Name
89*	Quartz-rich portion of a biotite migmatite.
90	Plagioclase-quartz-rich migmatite.
91	Coarse-grained quartz-rich migmatite.
92*	Fine and medium-grained biotite plagioclase-microcline granitic gneiss.
93	Microcline-rich portion of a migmatite.
94*	Coarse-grained biotite microcline-plagioclase tonalitic granofels.
95	Coarse-grained sillimanite-biotite plagioclase dioritic granofels.
96	Very fine-grained banded biotite-hornblende gneiss.
97	Microcline-rich portion of a biotite migmatite.
98*	Microcline-rich portion of a migmatite.
99	Coarse-grained biotite-rich tonalitic granofels.
100	Tourmaline plagioclase-rich pegmatite.
150*	Coarse-grained plagioclase-microcline alkali-feldspar granitic granofels.
151	Coarse-grained apatite-biotite plagioclase-microcline alkali-feldspar granitic granofels.
153	Medium and fine-grained plagioclase-microcline granitic gneiss.
154*	Coarse-grained biotite microcline-plagioclase tonalitic granofels.
155*	Coarse-grained muscovite-biotite plagioclase-microcline granitic granofels.

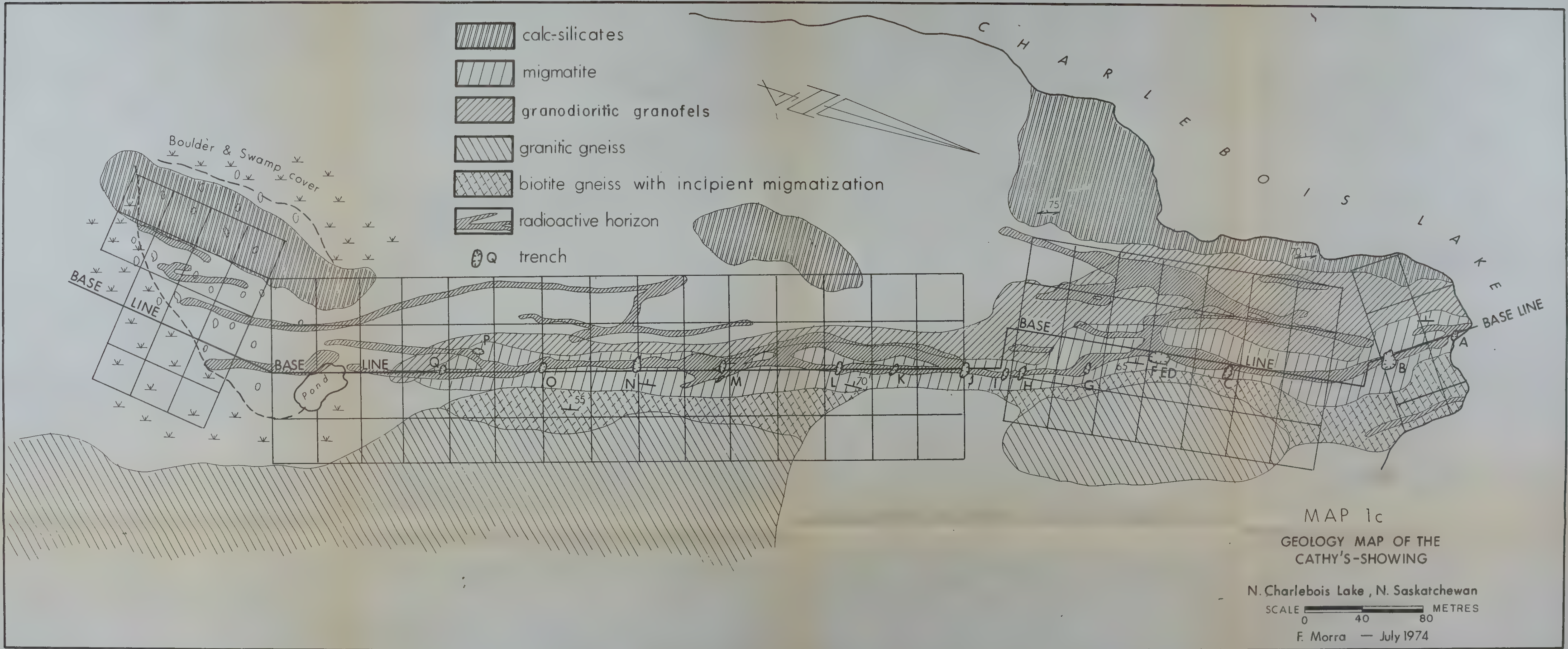
Sample No.	Rock Name
157	Microcline-rich pegmatite in contact with a muscovite-biotite plagioclase-microcline granitic gneiss.
161	Apatite-sphene microcline-rich hornblende gneiss.
162	Coarse-grained plagioclase-microcline alkali-feldspar granitic granofels.
163	Medium-grained molybdenite-bearing sphene-biotie plagioclase-microcline granitic granofels.
164	Medium-grained biotite microcline-plagioclase granitic granofels.
166	Coarse-grained biotite plagioclase-microcline syenitic granofels.
168	Fine-grained muscovite-biotite microcline-plagioclase tonalitic gneiss.
169	Fine and very fine-grained biotite plagioclase-microcline granitic gneiss.
202	Coarse-grained biotite microcline plagioclase granitic granofels.
203	Medium-grained biotite microcline-plagioclase granodioritic granofels.
204	Coarse-grained biotite microcline alkali-feldspar granitic granofels.
205	Coarse-grained biotite plagioclase-microcline granitic granofels (uraninite present).
206	Quartz-rich portion of a uraninite-molybdenite bearing biotite plagioclase migmatite.
207	Very fine-grained banded biotite-hornblende gneiss.

Sample No.	Rock Name
208	Plagioclase-microcline portion of a biotite migmatite.
210	Coarse-grained biotite plagioclase-microcline alkali-feldspar granitic granofels.
211	Medium-grained muscovite-biotite plagioclase-microcline granitic granofels (uraninite present).
212	Fine-grained banded sericite-biotite-hornblende-diopside gneiss.
213	Fine-grained biotite-hornblende gneiss.
214	Fine-grained biotite plagioclase hornblende-diopside calc-silicate.
215	Medium-grained biotite plagioclase-microcline granitic gneiss.
216	Microcline-plagioclase-rich portion of a biotite migmatite.
217	Medium-grained biotite plagioclase-microcline granitic gneiss.
221	Medium-grained muscovite-biotite microcline-plagioclase granitic granofels.
224	Tourmaline in a quartz vein. Portion of a very coarse-grained pegmatite.
228	Garnet quartz-rich portion of a biotite migmatite.
230*	Muscovite-biotite-tourmaline quartz-orthoclase pegmatite.
231	Coarse-grained uraninite-bearing biotite microcline-plagioclase granodioritic granofels.
233	Uraninite-molybdenite-bearing quartz-rich portion of a migmatite.

Sample No.	Rock Name
239	Porphyroblastic quartz-plagioclase-microcline portion of a migmatite.
240	Pyrite-bearing quartz-rich pyribolite.
242	Molybdenite-bearing quartz-rich portion of a biotite migmatite.

*: Modal analyses have been done over the specimen.


SPREKLEY LAKE
104° 50'
45'
104° 40'
59° 30'
LENIUK LAKE
UNMAPPED
UNMAPPED
HEISLER LK
CHARLEBOIS LAKE
SPREKLEY LAKE
CHESTNUT LAKE
FOX BAY
25'
DRAMNITZKE BAY
OTT LAKE
MACHETE LAKE
PEGASUS LAKE
UNMAPPED
HIGGINSON LAKE
104° 45'
59° 20'
59° 20'
GUPPY LAKE
UNMAPPED
UNMAPPED
104° 55'
CHARLEBOIS-HIGGINSON LAKE STRUCTURAL MAP
MAP AREA
N
SIMBOLS
Antiform (defined, overturned, approximate)
Synform (defined, approximate)
Fault (defined, assumed)
Foliation (vertical, inclined)
Drag fold (arrow indicates plunge)
Geological boundary
Limit of mapped area
SCALE:
0 500 1000
METRES
MAP No. 2
Franco Morra - Dec. '75



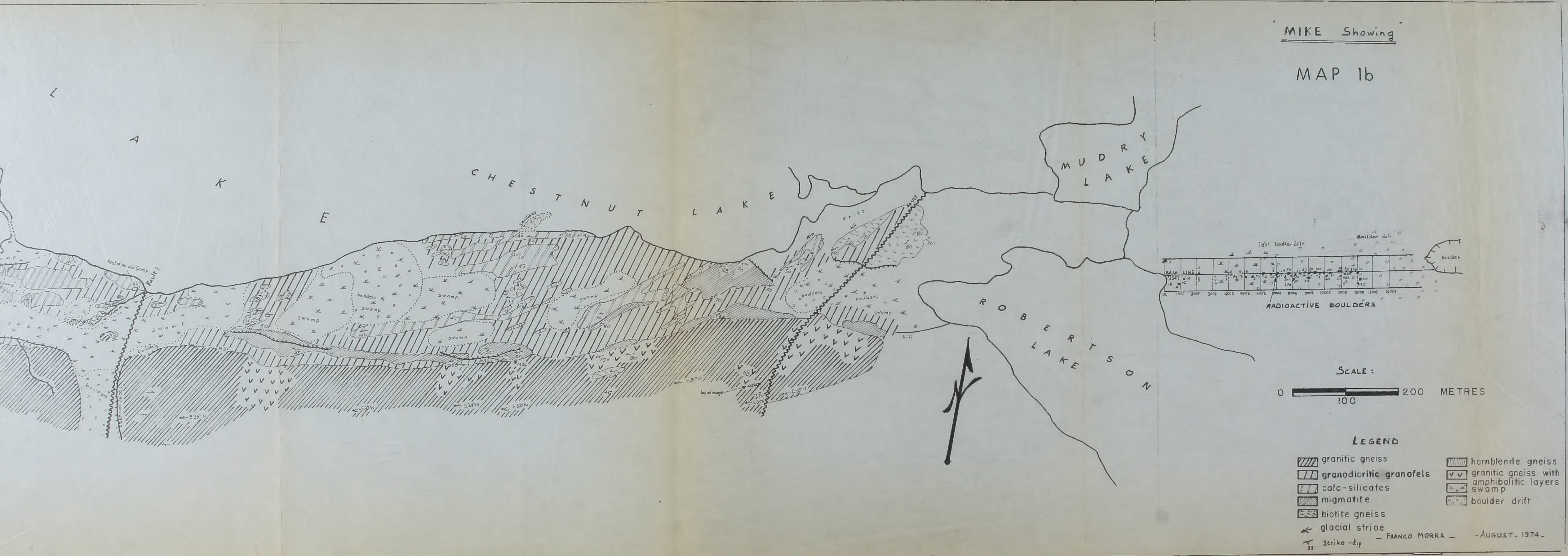
MAP 1c

GEOLOGY MAP OF THE CATHY'S-SHOWING

N. Charlebois Lake, N. Saskatchewan

F. Morra — July 1974


C H E S T N U T
L A K E
GLATIOTIS LAKE
McKLUSKY LAKE
VANNA LAKE
MORRA LAKE
Sand Hill
swamp
ponds
boulders
garnets
CLIFF
Fault
Fault ?
Rest of an old Camp
Sand Beach
Swamp & boulders
Stream


"MIKE Showing"
MAP 1b
L A K E
C H E S T N U T   L A K E
M U D R Y   L A K E
R O B E R T S O N   L A K E
swamp
boulders
boulders & swamp
drift
hill
fault ?
light boulder drift
Boulder drift
boulder
BASE LINE
RADIOACTIVE BOULDERS
SCALE:
0
100
200 METRES
LEGEND
granitic gneiss
granodioritic granofels
calc-silicates
migmatite
biotite gneiss
glacial striae
strike-dip
hornblende gneiss
granitic gneiss with amphibolitic layers
swamp
boulder drift
- FRANCO MORRA -
- AUGUST - 1974 -

SPREKLEY LAKE
LENIUK LAKE
UNMAPPED
UNMAPPED
HEISLER LK.
CHARLEBOIS LAKE
SPREKLEY LAKE
CHESTNUT LAKE
FOX BAY
DRAMNITZKE BAY
MACHETE LAKE
OTT LAKE
PEGASUS LAKE
UNMAPPED
HIGGINSON LAKE
MOOSE
GOOSE
MARCO
GUPPY LAKE
UNMAPPED
UNMAPPED
104° 50'
45'
104° 40'
59° 30'
59° 25'
25'
59° 20'
59° 20'
104° 55'
104° 45'
CHARLEBOIS-HIGGINSON LAKE GEOLOGICAL MAP
LEGEND
Glacial drift
Pink pegmatite dykes and irregular bodies
CHARLEBOIS LAKE COMPLEX
8 Quartzite
7 Biotite gneiss
6 Undifferentiated gneisses: 2-5-7
5 Hornblende gneiss and amphibolite
4 Calc-silicates
3 Migmatite
2 Granodioritic granofels
a b c Granitic and tonalitic gneiss; foliated, plagioclase-rich (b), with concordant amphibolite bands (a), less foliated type, microcline-rich (c).
SCALE
0 500 1000
METRES
MAP AREA
SYMBOLS
Antiform (overturned, defined, approximate)
Synform (defined, approximate)
Fault (defined, assumed)
Foliation (vertical, inclined)
Drag fold (arrow indicates plunge)
Geological boundary (defined, approximate, assumed)
Limit of geological mapping
▲340 Elevation in metres
Esker; glacial striae
Radioactive anomaly
Ⓐ1800 Age in m.y.
⑤ Specimen location
MAP No. 1
Franco Morra - Oct '75